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FINAL REPORT

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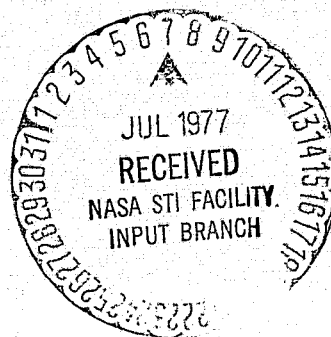


Table of Contents

Title Page.	1.
List of Principle Symbols and Acronyms.	3.
1. Summary	5.
2. Introduction.	6.
3. Principles of Operation	7.
4. Answers to Specific Criticisms of the EWEC Device . .	13.
5. Remaining Tasks	17.
6. References.	18.
Appendix A. Formulation of the Electromagnetic Fields at an EWEC Surface.	20.
Appendix B. Efficiency Calculations for Some EWEC Surfaces	36.
Appendix C. FORTRAN Program to Evaluate Efficiency . . .	85.

List of Principle Symbols and Acronyms

C_m	Coupling coefficient between incident wave and mth even waveguide mode.
$\vec{E}$	Electric field.
E_0^i	Incident electric field.
E_{0c}^m	Electric field of mth even waveguide mode.
E_{0s}^m	Electric field of mth odd waveguide mode.
E_0^n	Electric field of nth Floquet mode.
EWEC	Electromagnetic Wave Energy Conversion
F	Complex Fresnel integral.
$\vec{H}$	Magnetic field.
H_0^i	Incident magnetic field.
H_{0c}^m	Magnetic field of mth even waveguide mode.
H_{0s}^m	Magnetic field of mth odd waveguide mode.
H_0^n	Magnetic field of nth Floquet mode.
I	1. current; 2. integral.
k_0	Free space wave number.
k_{xc}^m, k_{yc}^m	Wave numbers for mth even waveguide mode.
k_{xs}^m, k_{ys}^m	Wave numbers for mth odd waveguide mode.
l	Length of corrugation.
N	N-type semiconductor.
P.	P-type semiconductor.
Re	Real part
S_m	Coupling coefficient between incident wave and mth odd waveguide mode.
$\tan \delta$	Loss tangent (dielectric).
$\tan \delta_m$	Loss tangent (magnetic media).
TE	Transverse Electric

T_M	Transverse Magnetic
V	Voltage.
Z_{mc}	Impedance of mth even waveguide mode.
Z_{ms}	Impedance of mth odd waveguide mode.
α	Half-angle of corrugation.
T_n	Reflection coefficient for mth waveguide mode.
ϵ	Permittivity.
η_0	Impedance of free space.
μ	Permeability.
θ	Angle of incidence.
σ	Conductivity.
ω	2π x frequency.

1. Summary.

This analytic investigation shows how the EWEC device, as used for solar-to-electric power conversion, is significantly different from solar cells, with respect to principles of operation. An optimistic estimate of efficiency is about 80% for a full-wave rectifying configuration with solar radiation normally incident. This compares favorably with the theoretical maximum for a CdTe solar cell (23.5%), as well as with the efficiencies of more familiar cells: Si (19.5%), InP (21.5%), and GaAs (23%).

The investigation also identifies some key technological issues that must be resolved before the EWEC device can be realized. Those issues include: the fabrication of a pn semiconductor junction with no permittivity resonances in the optical band; and the efficient channeling of the power received by countless microscopic horn antennas through a relatively few number of wires.

2. Introduction

The EWEC (Electromagnetic Wave Energy Conversion) device has been proposed by Bailey et al [1] as a means to convert radio waves in the optical band to either d.c. electric or to thermal power. Of chief interest is that the device may be significantly more efficient than the solar cell for converting solar radiation to electric power. For example, the best CdTe solar cell is theoretically about 23.5 % efficient [2]. Bailey estimates that the EWEC may be more than 50 % efficient. This report describes an analytic investigation to determine as rigorously as possible the precise efficiency of the EWEC device.

3. Principles of Operation

The chief component of the EVEC device is a corrugated surface as shown in Fig. 3.1. Each corrugation comes to a point so that there will be no scattering from a flat surface when solar radiation is incident from directly overhead (normal incidence). Only a two-dimensional cross section is shown. In actual fact, the corrugations may be tetrahedrons or cones. In any case, the dimensions are on the order of an optical wavelength, which ranges from 0.1 micron for ultraviolet to 1 micron for infrared. For example, the length of the taper λ might be 10 wavelengths, and the half-angle of the taper α might be chosen so that the aperture (distance between peaks) is no more than a few wavelengths. With that choice of dimensions, each trough may be regarded as a horn antenna.

Fig. 3.1 also shows two different possible polarizations for the incident optical radio wave, TE or TM. On the average, non-polarized light consists of equal parts TE and TM waves. The distinction is not important for the production of thermal power, but it is very important for the production of electric power.

If the device is used for thermal power production, then the corrugations are fabricated from lossy material. As the waves propagate into the horns they deliver power to the walls. The walls in turn dissipate the energy as heat.

The production of electric power is more complicated and was of chief concern in this study. The evolution of a suitable EVEC device is illustrated in Fig. 3.2. The figure shows how a wire dipole antenna is deformed into an antenna with two isosceles triangles for arms. The antenna is terminated with a half-wave rectifying circuit. Fig. 3.3 takes the evolution a step further by incorporating the diode into the antenna arms, which are then made of semiconducting material. Also shown is the equivalent circuit. This circuit has a maximum theoretical efficiency of 40.6 % [3].

The efficiency may be exactly doubled (to 81.2 %) by fabricating a full-wave rectifying circuit, as shown in Fig. 3.4.

Whether or not the full efficiency allowed by circuit theory

is obtained depends upon how well the horn antennas can capture the incident radio waves and transform them into useful waveguide modes. Calculations in Appendix B show that for a wide variety of materials, the horns are efficient like $\cos^2\theta$, where θ is the angle of incidence for the optical radio wave. Thus, for normally incident waves, the horns may be 100 % efficient. This efficiency does not depend critically upon size. Indeed, for TM waves, efficiency remains great even for very small half-angles of the taper (i.e. closely spaced corrugations.) Intuitively, this seems correct because the fundamental TM mode in a dielectric waveguide has no cutoff frequency and the horn may be regarded as a gently tapered waveguide. For TE waves, however, the efficiency vanishes for small half-angles. Again, this agrees with intuition.

The distinction between TE and TM waves is significant because the former are not as useful as the latter in the production of electric power. Both Figs. 3.3 and 3.4 show how TM waves excite currents I that flow in and out of the pn junction. TE waves will not excite currents with that direction of flow. Fortunately, referring back to Fig. 3.1, it is seen how a TE wave in the xy-plane is similar to a TM wave in the yz-plane. Thus, an EWEC surface with corrugations in both the x and z directions (e.g. tetrahedrons or cones) may exploit the TM and TE polarizations simultaneously.

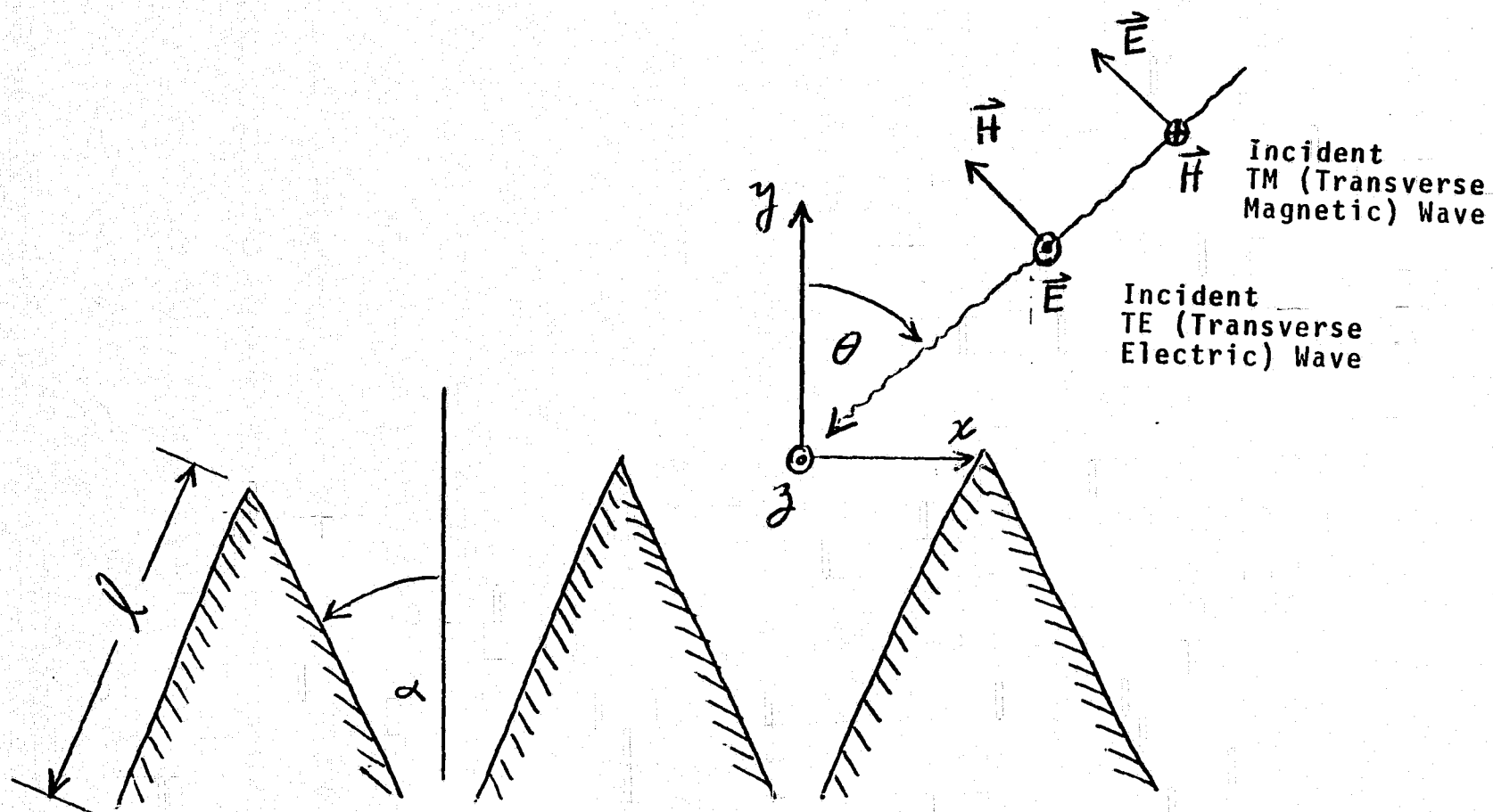
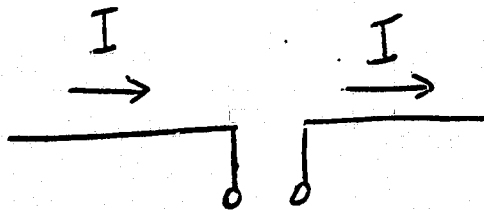
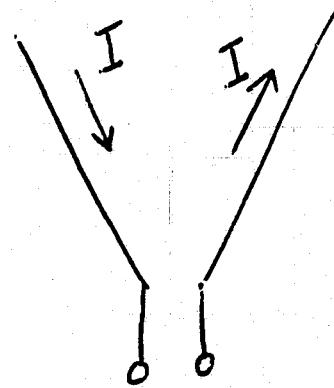


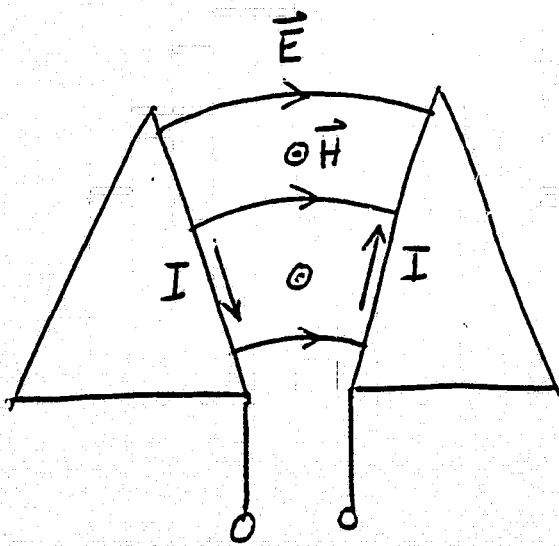
Fig. 3.1. Profile of an EVEC surface. How the corrugations are joined at the base depends upon whether thermal or electric power production is desired.



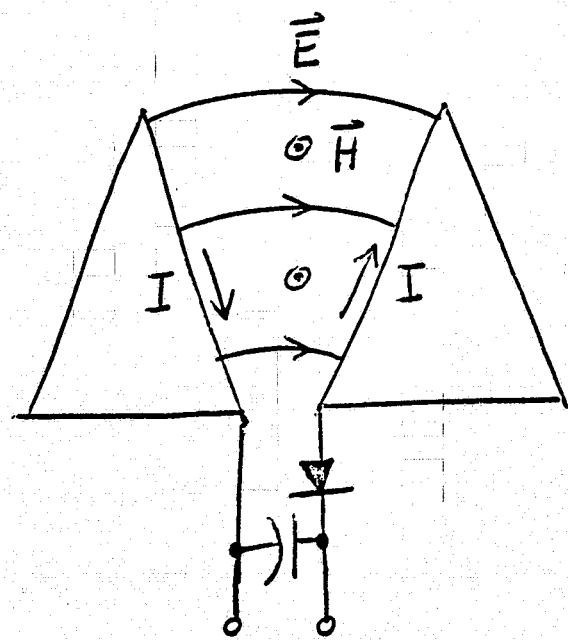
(a)



(b)

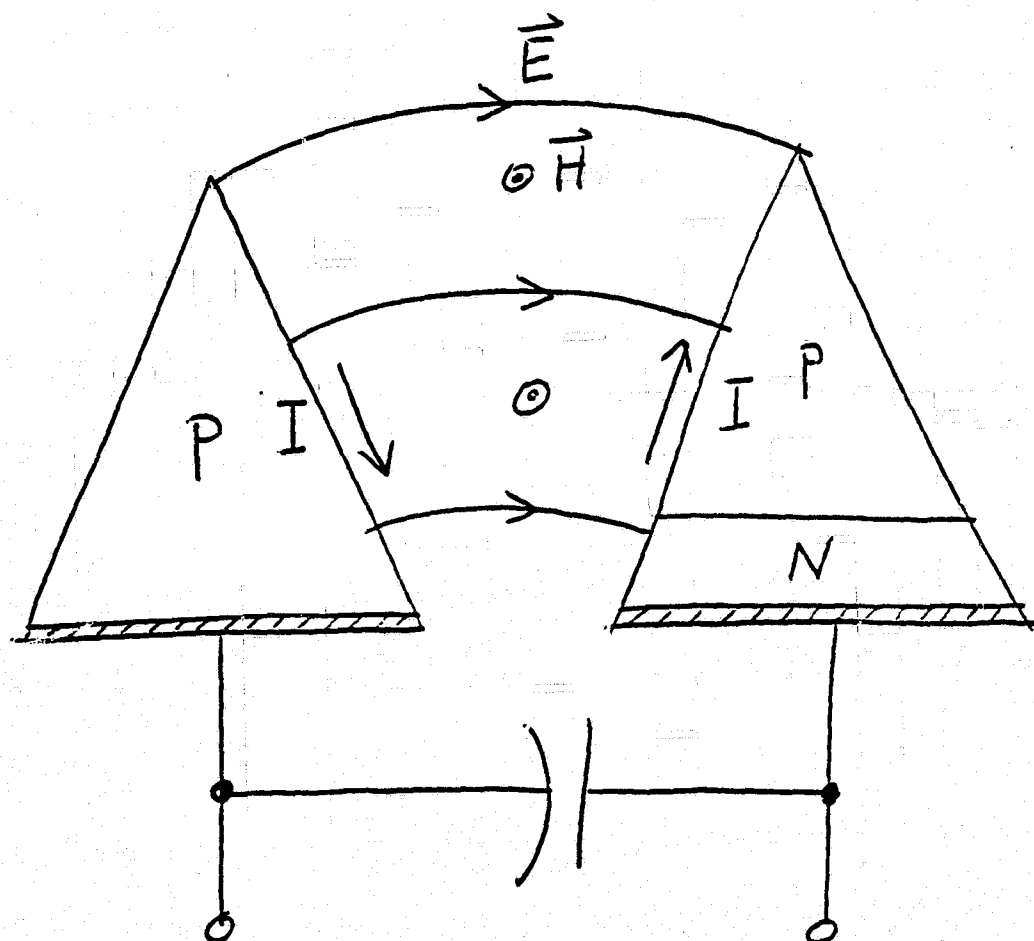


(c)

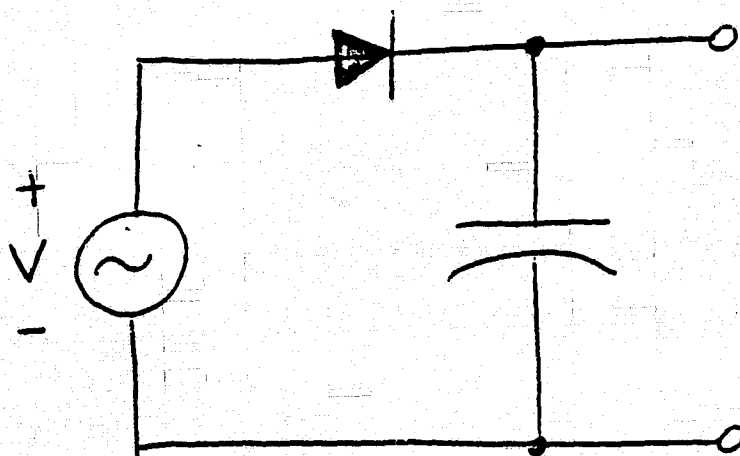


(d)

Fig. 3.2. Gradual transformation of a wire dipole antenna (a) into a section of the EWEC surface terminated by a half-wave rectifying circuit (d).

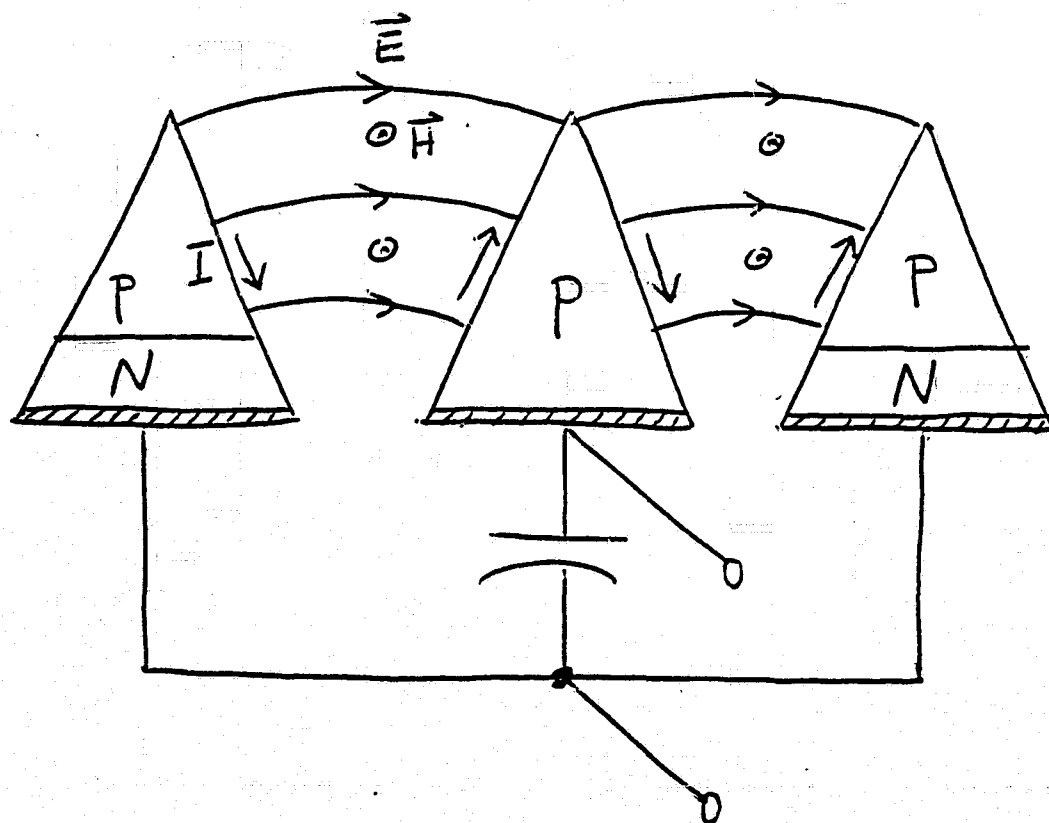


(a)

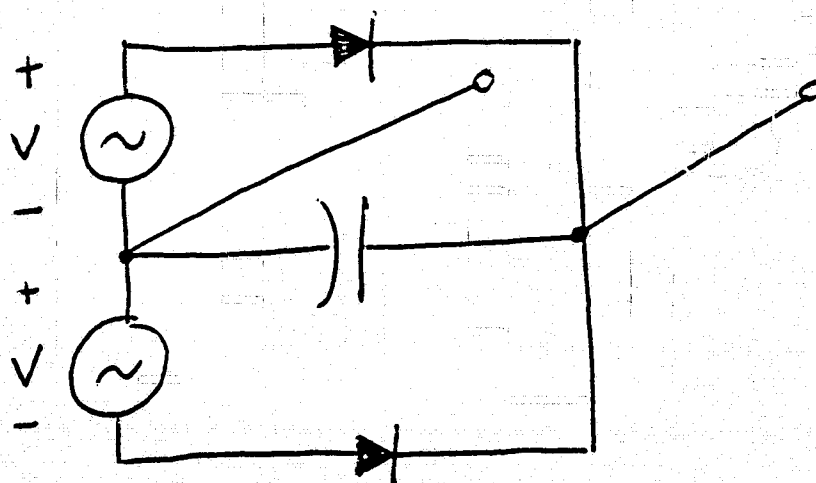


(b)

Fig. 3.3. Section of the EVEC surface similar to Fig. 3.2d, but with the diode incorporated into one of the corrugations. Also shown (b) is the equivalent circuit, which has a maximum theoretical efficiency of 40.6%.



(a)



(b)

Fig. 3.4. Improved configuration over that shown in Fig. 3.3. The equivalent circuit (b), which is a full-wave rectifier, has a maximum theoretical efficiency of 81.2%.

4. Answers to Specific Criticisms of the EVEC Device

This section will answer three specific criticisms against the EVEC device. The criticisms will be stated and discussed one by one.

● Fabrication of an EVEC device from semiconducting material is not practical because the dimensions must be on the order of interatomic distances.

DISCUSSION: A simple comparison of numbers dispels this claim. Interatomic spacings for Si and Ge are 5.4 Å and 5.7 Å, respectively [4]. In contrast, the wavelengths for ultraviolet and infrared radio waves are 1000 Å and 10,000 Å, respectively.

A different dimension characteristic of semiconductor pn junctions warrants more serious investigation, however. That dimension is the width of the space charge layer, which comprises the junction. It is given by the formula [4]:

$$w = \sqrt{\frac{2 \epsilon_r \epsilon_0}{q} \frac{N_A + N_D}{N_A N_D} \Delta V} \quad (4.1)$$

where ϵ_r = dielectric constant of the semiconductor = 10
 q = electronic charge = 1.6×10^{-19} coulomb
 N_A = acceptor doping density of p-type materials $\sim 10^{22}$ atoms/m³
 N_D = donor doping density of n-type material $\sim 10^{22}$ atoms/m³
 ΔV = potential difference across junction ~ 1 volt

Evaluation of this formula yields $w \sim 0.15$ micron, which is longer than an ultraviolet wavelength. It is not clear whether the formula is valid at optical frequencies, however, or whether the doping densities can be altered to decrease w . These are

important questions for a future investigation.

● The EWEC device is nothing more than a solar cell, and so it cannot be any more efficient.

DISCUSSION: How the EWEC device is significantly different from the solar cell is contained concisely in the formula for refractive index as a function of frequency [5]:

$$n^2 = 1 + \omega_p^2 \sum_m \frac{f_m}{\omega_m^2 - \omega^2 + j\delta_m\omega} \quad (4.2)$$

where

ω_p = plasma frequency
 f_m = oscillator strength
 ω_m = mth resonance
 δ_m = phenomenological damping factor
 ω = 2π x frequency
 j = $\sqrt{-1}$

The refractive index is related to the complex permittivity of the semiconducting material by the formula,

$$\epsilon = \epsilon' - j\epsilon'' = \epsilon_0 n^2 \quad (4.3)$$

Of chief interest in Eq. 4.2 is the difference $\omega_m^2 - \omega^2$. This causes the permittivity to behave as shown in Fig. 4.1. Thus, at frequencies near ω_m , the semiconducting material exhibits substantially changed properties that are the distinction between an electronic diode and a solar cell. It happens that most familiar semiconducting materials have resonances ω_m in the optical band because:

$$\hbar\omega_m = E_g$$

(4.4)

where $\hbar$ = Planck's constant/ 2π
 E_g = energy difference between a freely conducting electron and a valence electron

That is why conventional semiconductors become solar cells at optical frequencies, with the associated limitations in efficiency. In contrast, the EWEC device will be fabricated from semiconducting material with resonances outside the optical band. The search for candidate materials should be the subject for future study.

- White light is incoherent, so the EWEC surface has no gain and thus cannot capture any incident energy.

DISCUSSION: That white light is incoherent means that each horn antenna of the EWEC surface must operate independently. The signals received by the horns cannot be phase and/or amplitude weighted and then combined so as to form the response of a single antenna of extraordinary gain. This is because there is no known phase or amplitude relationship among the different signals received. Each horn is still capable of extracting power separately from the incident radio wave, however, and the powers from each horn are added to obtain the total power received by the EWEC surface.

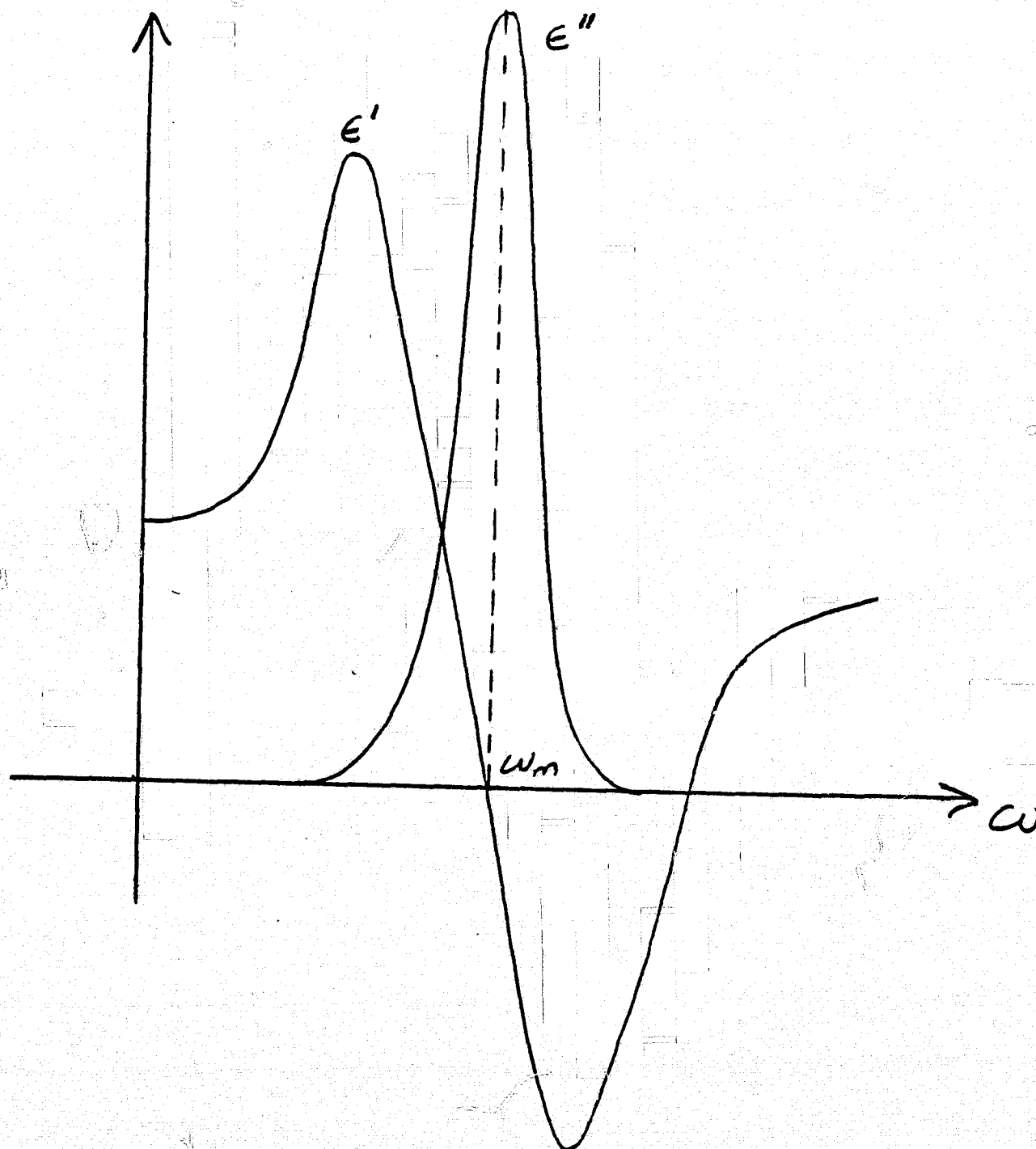


Fig. 4.1. The refractive index is not constant but a function of frequency, with resonances as shown here. Most familiar semiconductors have resonances at optical frequencies which is why they behave as solar cells instead of electronic diodes.

5. Remaining Tasks

This study has verified that a corrugated surface can efficiently capture incident optical radio waves. Before the EWEC device can be accepted as a viable means of solar-to-electric power conversion, however, the following questions must be resolved:

- Are semiconducting materials without resonances in permittivity at optical frequencies realizable?
- Can a pn junction with a space charge layer smaller than an optical wavelength be realized?
- How can the rectified power output from each microscopic horn antenna be efficiently channeled through a relatively few number of wires?

These additional questions follow, once the EWEC device is accepted as feasible:

- Can the EWEC device be extended for use outside the visible spectrum? What are the upper and lower limits?
- Can the dimensions of the corrugations be optimized? By what criteria?

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Appendix A. Formulation of the Electromagnetic Fields at an EWEC Surface.

This section outlines a detailed formulation of the electromagnetic fields at the EWEC surface. Discussion of these fields will provide insight into the operation of the EWEC device.

Fig. A.1 shows a profile of the surface. The corrugations are isosceles triangles. Other triangles might be used, but the mathematical analysis becomes more difficult. The most important feature is that the corrugations come to sharp points. If the tips were instead blunt, then they would be flat-plate scatterers for the incident electromagnetic wave, and thus decrease the efficiency of the surface as a receiver or absorber. The figure also shows the two possible independent polarizations for the incident wave, TE (transverse electric) or TM (transverse magnetic).

Fig. A.2 shows the trough between two corrugations and the geometric parameters important to the analysis, including the angle of incidence for the electromagnetic wave. Also shown are the constants that characterize the material from which the surface is fabricated.

The types of waves that may exist at the EWEC surface are shown in Fig. A.3. The incident wave excites scattered waves, or Floquet modes, which propagate along the surface (in the $+x$ or $-x$ directions); and waveguide modes which propagate into the trough (in the $-y$ direction.) A TE incident wave will excite only TE Floquet modes and TE waveguide modes. Similarly, a TM incident wave will excite only TM waves. Tables A.1 and A.2 show formulas for incident waves. Tables A.3 and A.4 show formulas for Floquet modes.

Exact formulas for bound modes in a trough, or linearly tapered waveguide, are not known except in cases of a few special materials, such as a perfect conductor. A good approximation is possible, however. To this end, Fig. A.4 shows how the trough may be regarded as a gradually deformed parallel-plate waveguide.

Exact field solutions for the latter are known. The solutions for the former are nearly the same. The difference is that the plane of constant phase is curved instead of flat. Mathematically, this difference is described by multiplying the solutions for the parallel-plate waveguide by a quadratic phase factor. The resulting formulas for waveguide modes in the trough are shown in Tables A.5-A.8. The modes may be of even or odd symmetry. In general, an incident wave will excite modes of both symmetries.

The amplitudes and phases of the Floquet and waveguide modes relative to the incident wave are determined by requiring that the tangential electric and magnetic fields be continuous across the aperture of the trough. The two simultaneous equations expressing this requirement are shown in Tables A.9 and A.10, for TE waves. The corresponding equations for TM waves are of identical form.

Solution of the equations of continuity may be achieved in a variety of ways. Point matching, the method of moments, and Fourier analysis are three possibilities. What is desired, however, is not an exact description of the electromagnetic field, but a calculation of efficiency. There are more direct ways to do this.

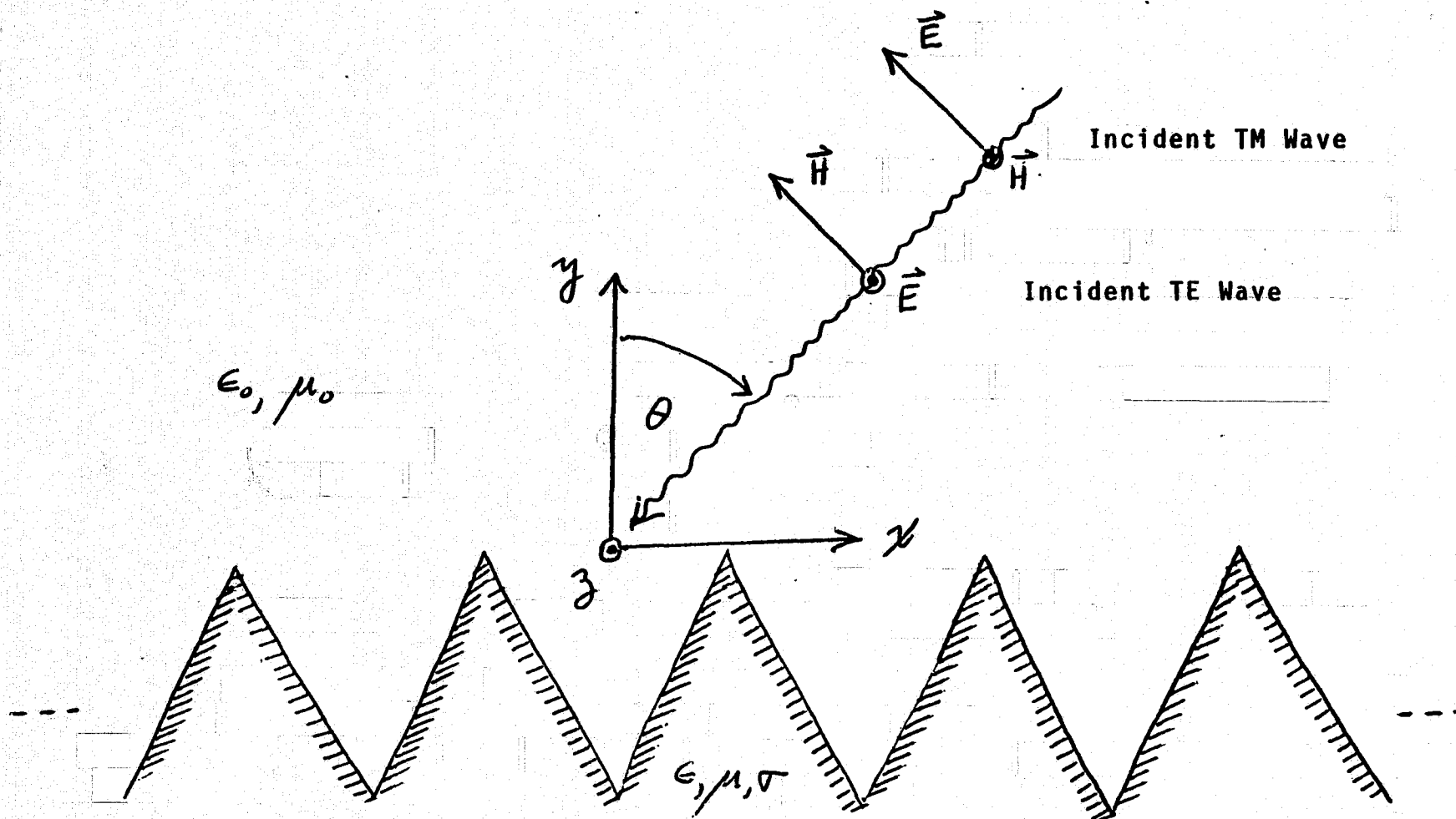


Fig. A.1. Two-dimensional EWE surface, showing corrugations and the two fundamental types of incident electromagnetic wave.

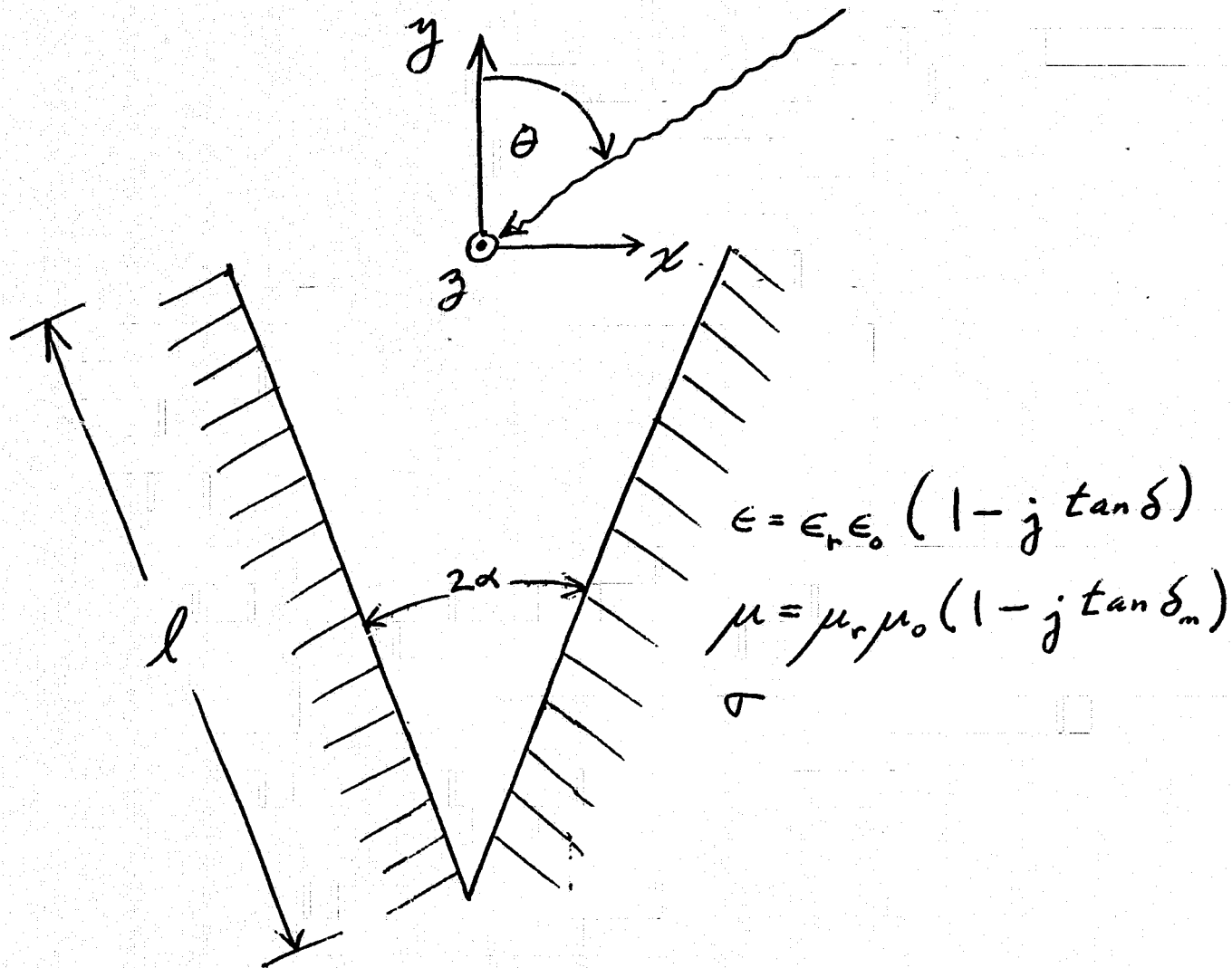


Fig. A.2. Fundamental geometric and electromagnetic parameters for the corrugated surface. Also shown is a coordinate system and the angle of incidence.

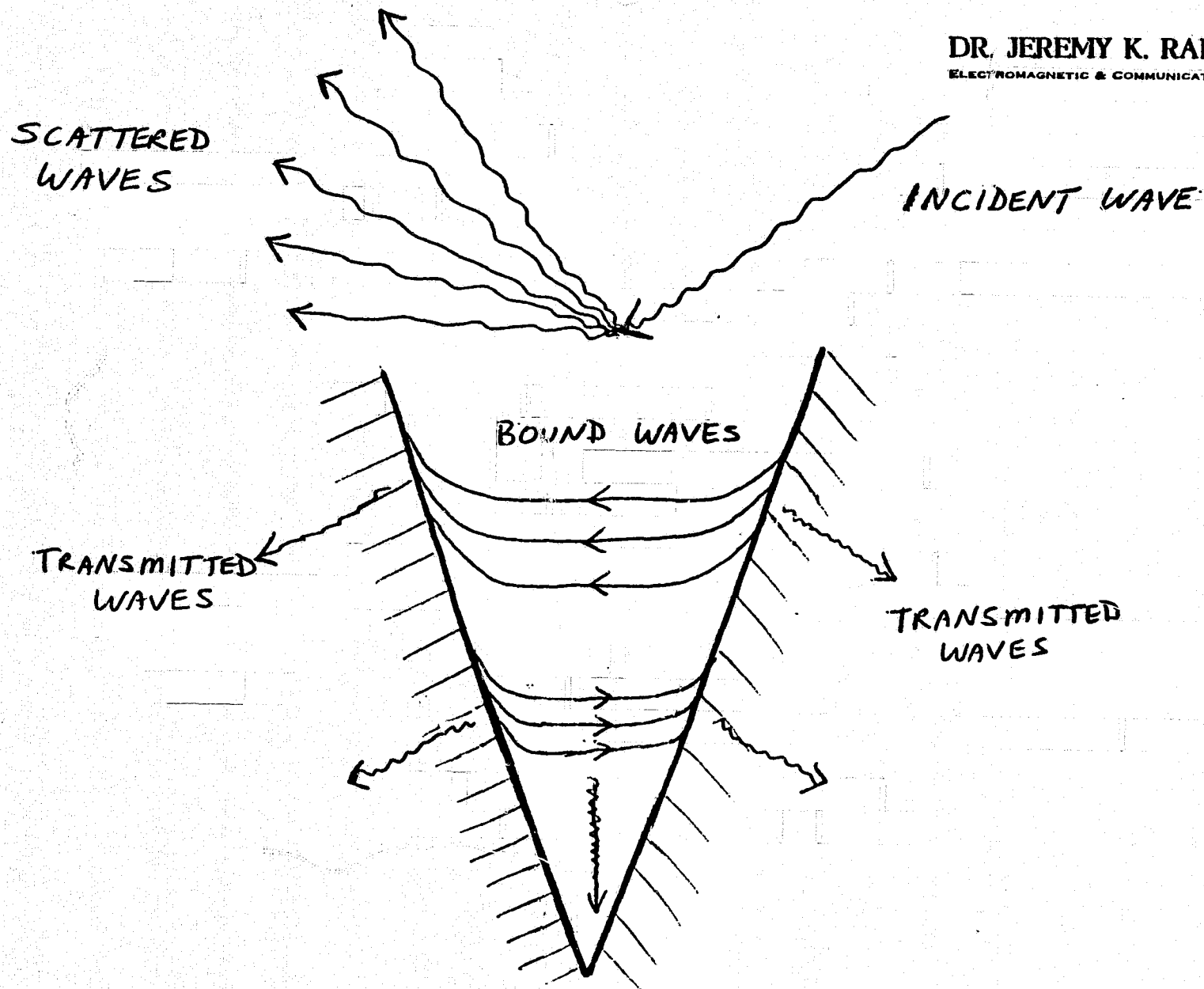


Fig. A.3. Types of waves that exist at the corrugated EVEC surface. The bound waves deliver energy to the medium by way of transmitted waves.

$$E_z^i = E_0^i e^{j\psi_i}$$

$$H_x^i = -\frac{\cos\theta}{\eta_0} E_0^i e^{j\psi_i}$$

$$H_y^i = \frac{\sin\theta}{\eta_0} E_0^i e^{j\psi_i}$$

$$\psi_i = k_0 (x \sin\theta + y \cos\theta)$$

Table A.1. Formulas describing an incident TE (transverse electric) wave.

$$H_z^i = H_0^i e^{j\psi_i}$$

$$E_x^i = \eta_0 \cos \theta H_0^i e^{j\psi_i}$$

$$E_y^i = -\eta_0 \sin \theta H_0^i e^{j\psi_i}$$

$$\psi_i = k_0 (x \sin \theta + y \cos \theta)$$

Table A.2. Formulas describing an incident TM (transverse magnetic) wave.

$$E_z^n = E_0^n e^{j\psi_n}$$

$$H_x^n = \frac{1}{\eta_0} \sqrt{1 - \left(\sin \theta + \frac{n\pi}{k_0 l \sin \alpha} \right)^2} E_0^n e^{j\psi_n}$$

$$H_y^n = \frac{1}{\eta_0} \left(\sin \theta + \frac{n\pi}{k_0 l \sin \alpha} \right) E_0^n e^{j\psi_n}$$

$$\psi_n = k_0 x \left(\sin \theta + \frac{n\pi}{k_0 l \sin \alpha} \right) - k_0 y \sqrt{1 - \left(\sin \theta + \frac{n\pi}{k_0 l \sin \alpha} \right)^2}$$

$$|n| = 0, 1, 2, 3, \dots$$

Table A.3. Formulas describing scattered TE waves. There are an infinity of these waves, one for each value of the integer n .

$$H_z^n = H_0^n e^{j\psi_n}$$

$$E_x^n = -\eta_0 \sqrt{1 - \left(\sin \theta + \frac{n\pi}{k_0 l \sin \alpha} \right)^2} H_0^n e^{j\psi_n}$$

$$E_y^n = -\eta_0 \left(\sin \theta + \frac{n\pi}{k_0 l \sin \alpha} \right) H_0^n e^{j\psi_n}$$

$$\psi_n = k_0 x \left(\sin \theta + \frac{n\pi}{k_0 l \sin \alpha} \right) - k_0 y \sqrt{1 - \left(\sin \theta + \frac{n\pi}{k_0 l \sin \alpha} \right)^2}$$

$$|n| = 0, 1, 2, 3, \dots$$

Table A.4. Formulas describing scattered TM waves. There are an infinity of these waves, one for each value of the integer n .

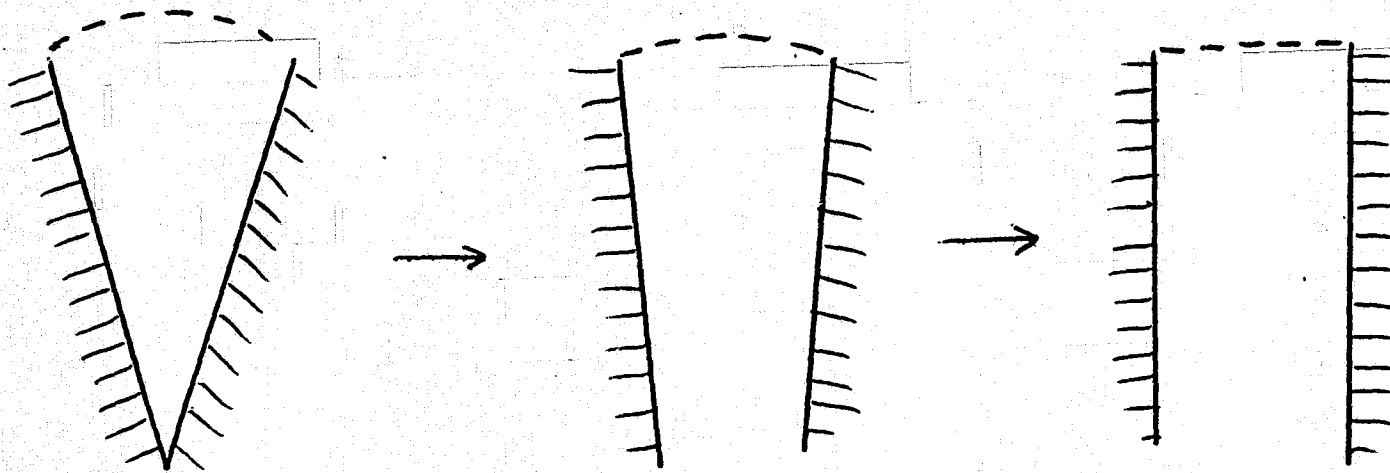


Fig. A.4. As the trough is deformed into a parallel-plate waveguide, the electromagnetic field is approximately unchanged except for the plane of constant phase (shown by the dashed line.) Thus, the field across the aperture of the trough may be expressed as the well known field of the parallel-plate waveguide, multiplied by a quadratic phase shift.

$$E_z = \sum_{m=0}^{\infty} E_{0c}^m \cos(k_{xc}^m x) e^{-j \frac{k_{yc}^m x^2}{2l \cos \alpha}} e^{j k_{yc}^m y}$$

$$H_x = -\frac{1}{\eta_0 k_0} \sum_{m=0}^{\infty} E_{0c}^m k_{yc}^m \cos(k_{xc}^m x) e^{-j \frac{k_{yc}^m x^2}{2l \cos \alpha}} e^{j k_{yc}^m y}$$

k_{xc}^m is the m^{th} solution of:

$$(k_{xc}^m l \sin \alpha) \tan(k_{xc}^m l \sin \alpha) = j \frac{\eta_0}{\eta} k_0 l \sin \alpha$$

$$k_{yc}^m = \sqrt{k_0^2 - (k_{xc}^m)^2}$$

Table A.5. Formulas for bound TE waves of even symmetry.

$$E_z = \sum_{m=0}^{\infty} E_{0s}^m \sin(k_{xs}^m x) e^{-j \frac{k_{ys}^m x^2}{2l \cos \alpha}} e^{j k_{ys}^m y}$$

$$H_x = -\frac{1}{\eta_0 k_0} \sum_{m=0}^{\infty} E_{0s}^m k_{ys}^m \sin(k_{xs}^m x) e^{-j \frac{k_{ys}^m x^2}{2l \cos \alpha}} e^{j k_{ys}^m y}$$

k_{xs}^m is the m^{th} solution of:

$$(k_{xs}^m l \sin \alpha) \cot(k_{xs}^m l \sin \alpha) = -j \frac{\eta_0}{\eta} k_0 l \sin \alpha$$

$$k_{ys}^m = \sqrt{k_0^2 - (k_{xs}^m)^2}$$

Table A.6. Formulas for bound TE waves of odd symmetry.

$$H_z = \sum_{m=0}^{\infty} H_{0c}^m \cos(k_{xc}^m x) e^{-j \frac{k_{yc}^m x^2}{2l \cos \alpha}} e^{j k_{yc}^m y}$$

$$E_x = \frac{\eta_0}{k_0} \sum_{m=0}^{\infty} H_{0c}^m k_{yc}^m \cos(k_{xc}^m x) e^{-j \frac{k_{yc}^m x^2}{2l \cos \alpha}} e^{j k_{yc}^m y}$$

32.

k_{xc}^m is the m th solution of:

$$(k_{xc}^m l \sin \alpha) \tan(k_{xc}^m l \sin \alpha) = j \frac{\eta_0}{\gamma_0} k_0 l \sin \alpha$$

$$k_{yc}^m = \sqrt{k_0^2 - (k_{xc}^m)^2}$$

Table A.7. Formulas for bound TM waves of even symmetry.

$$H_z = \sum_{m=0}^{\infty} H_{0s}^m \sin(k_{xs}^m x) e^{-j \frac{k_{ys}^m x^2}{2l \cos \alpha}} e^{j k_{ys}^m y}$$

$$E_x = \frac{\eta_0}{k_0} \sum_{m=0}^{\infty} H_{0s}^m k_{ys}^m \sin(k_{xs}^m x) e^{-j \frac{k_{ys}^m x^2}{2l \cos \alpha}} e^{j k_{ys}^m y}$$

k_{xs}^m is the m^{th} solution of:

$$(k_{xs}^m l \sin \alpha) \cot(k_{xs}^m l \sin \alpha) = -j \frac{\eta_0}{k_0} k_0 l \sin \alpha$$

$$k_{ys}^m = \sqrt{k_0^2 - (k_{xs}^m)^2}$$

Table A.8. Formulas for bound TM waves of odd symmetry.

$$\begin{aligned}
 & E_0^i e^{j k_0 x \sin \theta} + \sum_{n=-\infty}^{\infty} E_0^n e^{j k_0 x \left(\sin \theta + \frac{n \pi}{k_0 l \sin \theta} \right)} \\
 &= \sum_{m=0}^{\infty} E_{0c}^m \cos(k_{xc}^m x) e^{-j \frac{k_{yc}^m x^2}{2l \cos \theta}} \\
 &\quad + \sum_{m=0}^{\infty} E_{0s}^m \sin(k_{xs}^m x) e^{-j \frac{k_{ys}^m x^2}{2l \cos \theta}}
 \end{aligned}$$

Table A.9. Equation for the continuity of the tangential electric field across the aperture of the trough, for TE waves.

$$-k_0 \cos \theta E_0^i e^{j k_0 x \sin \theta}$$

$$+ \sum_{n=-\infty}^{\infty} E_0^n k_0 \sqrt{1 - \left(\sin \theta + \frac{n r}{k_0 l \sin \alpha} \right)^2} e^{j k_0 x \left(\sin \theta + \frac{n r}{k_0 l \sin \alpha} \right)}$$

$$= - \sum_{m=0}^{\infty} E_{oc}^m k_{yc}^m \cos(k_{xc}^m x) e^{-j \frac{k_{yc}^m x^2}{2 l \cos \alpha}}$$

$$- \sum_{m=0}^{\infty} E_{os}^m k_{ys}^m \sin(k_{xs}^m x) e^{-j \frac{k_{ys}^m x^2}{2 l \cos \alpha}}$$

Table A.10. Equation for the continuity of the tangential magnetic field across the aperture of the trough, for TE waves.

Appendix B. Efficiency Calculations for Some EVEC Surfaces.

This section outlines a relatively short method for calculating the efficiency of an EVEC surface. The method relies on the conservation of power and the formulas for the waveguide modes described in Appendix A.

Fig. B.1 shows the directions in which power propagates. The incident power propagates in the same direction as the radio wave carrying it. At the aperture of the trough, the power flows in different directions. The Floquet modes carry power along the surface (in the $+x$ and $-x$ directions.) Negligible amounts of this power are absorbed or received by the surface, which for these modes serves as a surface waveguide or transmission line. If the EVEC surface were infinitely long in the x dimension, the Floquet modes would propagate unchanged forever. For finite lengths, they partly reflect and partly radiate at the ends, as with any endfire antenna.

The remaining power is transmitted into the troughs (in the $-y$ direction) by waveguide modes or reflected back into space (in the $+y$ direction.) The transmitted power in turn may be absorbed or dissipated by the walls of the trough.

Conservation of time-average power at the apertures of the troughs requires that, if the incident power is unity, then the Floquet modes carry power $\sin^2\theta$, and the reflected and transmitted waves carry total power $\cos^2\theta$. Of the latter power, the part that is transmitted depends upon how well the incident radio wave couples to the waveguide modes. The coupling is a function of two phenomena:

- The incident wave must match one or more waveguide modes in spatial dependence across the aperture (i.e. in the x direction.) This phenomenon is called phase matching.
- The incident wave must match the same waveguide modes in impedance normal to the aperture (i.e. the wave

impedance in the -y direction.) This is equivalent to requiring continuity of the tangential electric and magnetic fields across the aperture.

Phase matching can be expressed quantitatively as the coherence between the spatial dependence of the incident wave and that of a waveguide mode:

$$C_m = \int_{-l \sin \alpha}^{l \sin \alpha} dx \cos(k_{xc}^m x) e^{-j \frac{k_{ys}^m x^2}{2l \cos \alpha}} e^{-j k_0 x \sin \theta} \quad (B.1)$$

for even modes, and:

$$S_m = \int_{-l \sin \alpha}^{l \sin \alpha} dx \sin(k_{xs}^m x) e^{-j \frac{k_{ys}^m x^2}{2l \cos \alpha}} e^{-j k_0 x \sin \theta} \quad (B.2)$$

for odd modes. These integrals may be evaluated in terms of well known functions:

$$C_m = \frac{1}{4l \sin \alpha} [I(a, b^-, x) - I(a, b^-, -x) + I(a, b^+, x) - I(a, b^+, -x)] \quad (B.3)$$

$$S_m = \frac{1}{j^4 l \sin \alpha} \left[I(a, b^-, x) - I(a, b^-, -x) - I(a, b^+, x) + I(a, b^+, -x) \right] \quad (\text{B.4})$$

where

$$a = \frac{k_y^m}{2l \cos \alpha}$$

$$b^\pm = k_0 \sin \theta \pm k_x^m$$

$$x = l \sin \alpha$$

In the formulas for a and b , subscripts c and s must be added to the quantities k_y^m and k_x^m , as appropriate. The function I may be expressed in terms of the complex Fresnel integral:

$$I(a, b, x) = \sqrt{\frac{\pi}{2a}} e^{j \frac{b^2}{4a}} F \left[\sqrt{\frac{2}{\pi a}} \left(ax + \frac{b}{2} \right) \right] \quad (\text{B.5})$$

where $F = C - jS$

Impedance matching is expressed quantitatively in terms of the reflection coefficient:

$$\Gamma_m = \frac{Z_i - Z_m}{Z_i + Z_m} \quad (\text{B.6})$$

where Z_i = wave impedance of the incident wave in the $-y$ direction.
 Z_m = impedance of the m th waveguide mode in the $-y$ direction.

Table B.1 gives formulas for Z_i and Z_m .

In terms of the correlation coefficients C_m and S_m and the reflection coefficient T_m , the power coupled by the incident wave to the m th even TE waveguide mode is:

$$P_m = K (1 - |T_m|^2) \int_{-l \sin \alpha}^{l \sin \alpha} dx \operatorname{Re} \left(\frac{|C_m|^2}{Z_{mc}} \right) \cos^2(k_{xc}^m x) \quad (\text{B.7})$$

Expressions are similar for the power coupled to odd TE modes and to TM modes. The integrals may be evaluated to obtain the expressions shown in Table B.2. The constant K is determined by requiring that the transmitted and reflected powers sum to the normally incident power. The result is:

$$K = \cos^2 \theta \left\{ \sum_{m=1}^{\infty} |C_m|^2 \operatorname{Re} \left(\frac{1}{Z_{mc}} \right) \left[1 + \frac{\sin(2k_{xc}^m l \sin \alpha)}{2k_{xc}^m l \sin \alpha} \right] + |S_m|^2 \operatorname{Re} \left(\frac{1}{Z_{ms}} \right) \left[1 - \frac{\sin(2k_{xs}^m l \sin \alpha)}{2k_{xs}^m l \sin \alpha} \right] \right\}^{-1} \quad (\text{B.8})$$

for TE modes. The result for TM modes is obtained by replacing $1/Z_m$ by Z_m .

Finally, the efficiency is the ratio of transmitted power to total power. The formula for TE waves is given in Table B.3.

The formulas for efficiency were evaluated for a variety of material constants and half-angles of the taper. The results are shown in Tables B.4-B.23 and in Figs. B.4-B.23. In general, they show that any horn becomes efficient like $\cos^2 \theta$, if the aperture is a few wavelengths across. As the aperture is made smaller, how-

ever, the horn becomes much less efficient for TE than for TM waves. Fig. B.4 shows that for TE waves and an aperture of 0.32 wavelengths, efficiency is no greater than about 66%. In contrast, Fig. B.8 shows that for TM waves and an aperture of 0.08 wavelengths, efficiency is as great as 93%. This behavior agrees with intuition. The horn may be regarded as a gently linearly-tapered waveguide with dielectric walls. The fundamental TM mode in such a waveguide has no cutoff frequency and is capable of transmitting power efficiently at any wavelength. If the horn were fabricated of magnetic material rather than a dielectric, then this behavior would be characteristic of the fundamental TE mode instead.

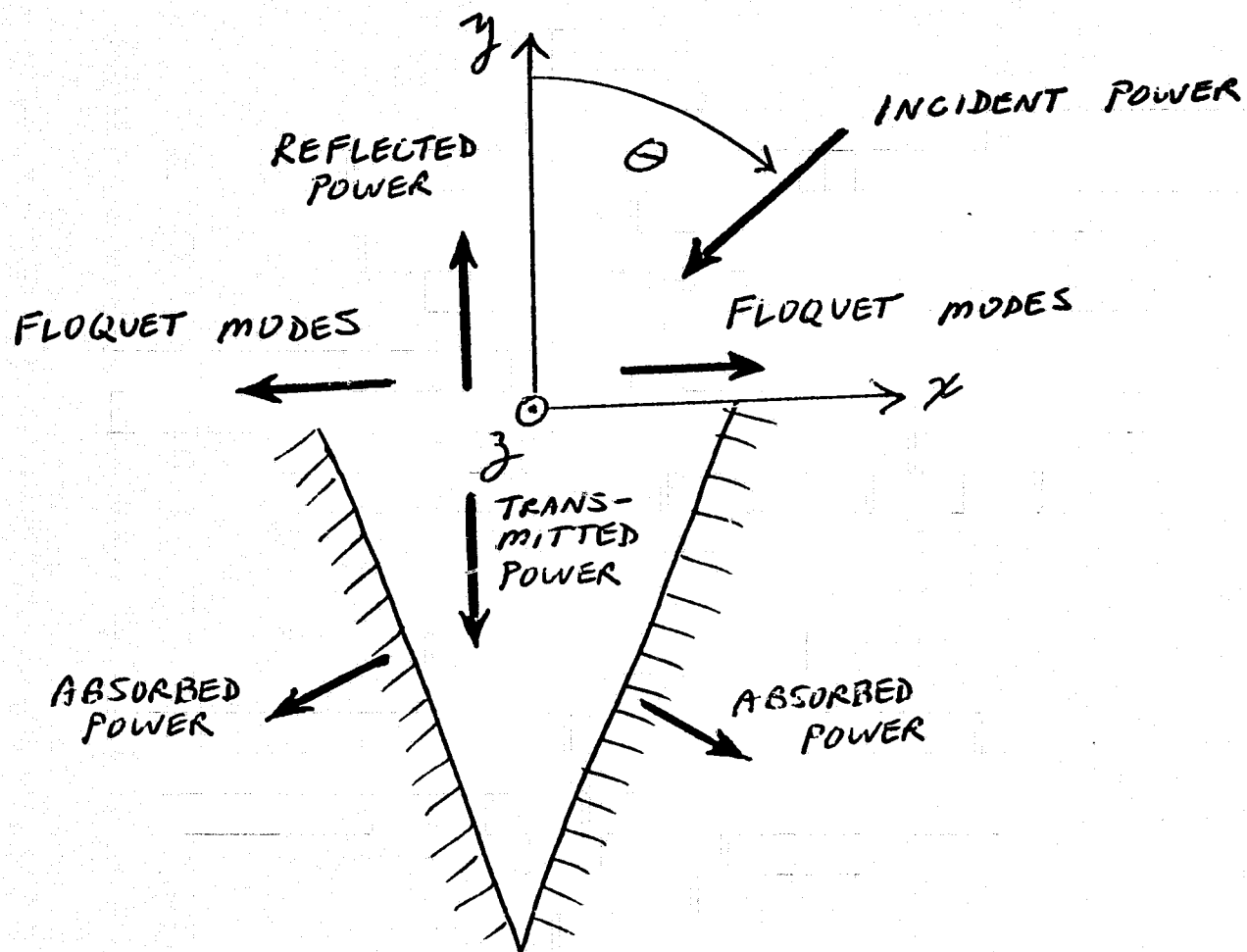


Fig. B.1. Directions of power flow at the EVEC surface. The efficiency is the ratio of transmitted power to incident power.

	TE	TM
Incident Wave	$-\frac{\eta_0}{\cos \theta}$	$-\eta_0 \cos \theta$
Mth Waveguide Mode	$-\frac{\eta_0 k_0}{k_y^m}$	$-\frac{\eta_0 k_y^m}{k_0}$

Table B.1. Impedances normal to the aperture of the trough (in the -y direction.)

	TE	TM
Mth Even Mode	$K C_m ^2 \operatorname{Re} \left(\frac{1}{Z_{mc}} \right) \cdot$ $\left[1 + \frac{\sin(2k_{xc}^m l \sin \alpha)}{2k_{xc}^m l \sin \alpha} \right]$	$K C_m ^2 \operatorname{Re} (Z_{mc})$ $\left[1 + \frac{\sin(2k_{xc}^m l \sin \alpha)}{2k_{xc}^m l \sin \alpha} \right]$
Mth Odd Mode	$K S_m ^2 \operatorname{Re} \left(\frac{1}{Z_{ms}} \right)$ $\left[1 - \frac{\sin(2k_{xs}^m l \sin \alpha)}{2k_{xs}^m l \sin \alpha} \right]$	$K S_m ^2 \operatorname{Re} (Z_{ms})$ $\left[1 - \frac{\sin(2k_{xs}^m l \sin \alpha)}{2k_{xs}^m l \sin \alpha} \right]$

Table B.2. Time-average power coupled by the incident wave to the mth waveguide mode. K is a normalization constant.

$$\eta_{\text{eff}} = \cos^2 \theta \left\{ \sum_{m=1}^{\infty} (1 - |\Gamma_m|^2) |C_m|^2 \operatorname{Re} \left(\frac{1}{Z_{mc}} \right) \right.$$

$$\left[1 + \frac{\sin(2k_{xc}^m l \sin \alpha)}{2k_{xc}^m l \sin \alpha} \right] + (1 - |\Gamma_m|^2) |S_m|^2 \operatorname{Re} \left(\frac{1}{Z_{ms}} \right) \cdot$$

$$\left[1 - \frac{\sin(2k_{xs}^m l \sin \alpha)}{2k_{xs}^m l \sin \alpha} \right] \left. \right\} / \left\{ \sum_{m=1}^{\infty} |C_m|^2 \operatorname{Re} \left(\frac{1}{Z_{mc}} \right) \right.$$

$$\left[1 + \frac{\sin(2k_{xc}^m l \sin \alpha)}{2k_{xc}^m l \sin \alpha} \right] + |S_m|^2 \operatorname{Re} \left(\frac{1}{Z_{ms}} \right) \cdot$$

$$\left[1 - \frac{\sin(2k_{xs}^m l \sin \alpha)}{2k_{xs}^m l \sin \alpha} \right] \left. \right\}$$

Table B.3. Efficiency of the EWE surface for TE waves. The formula for TM waves is of the same form, except that $1/Z_m$ must be replaced by Z_m .

TABLE B.4

TE WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 0.500 DEGREES
 DIELECTRIC CONSTANT= 10.000 LOSS TANGENT= 0.000
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 0.000 MHOS/METER

IMPEDANCE OF MEDIUM= 0.11913E 03 + J 0.00000E 00 OHMS

FIRST 1 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.15884E 08	0.52498E 07	0.69757E 07	-0.11954E 08

FIRST 1 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.29564E 08	0.98738E 07	0.10600E 08	-0.27539E 08

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE	EFFICIENCY
0.00000E 00	0.66209E 02
0.60000E 01	0.65286E 02
0.12000E 02	0.62578E 02
0.18000E 02	0.58255E 02
0.24000E 02	0.52583E 02
0.30000E 02	0.45898E 02
0.36000E 02	0.38583E 02
0.42000E 02	0.31043E 02
0.48000E 02	0.23686E 02
0.54000E 02	0.16896E 02
0.60000E 02	0.11019E 02
0.66000E 02	0.63244E 01
0.72000E 02	0.29738E 01
0.78000E 02	0.97557E 00
0.84000E 02	0.13394E 00

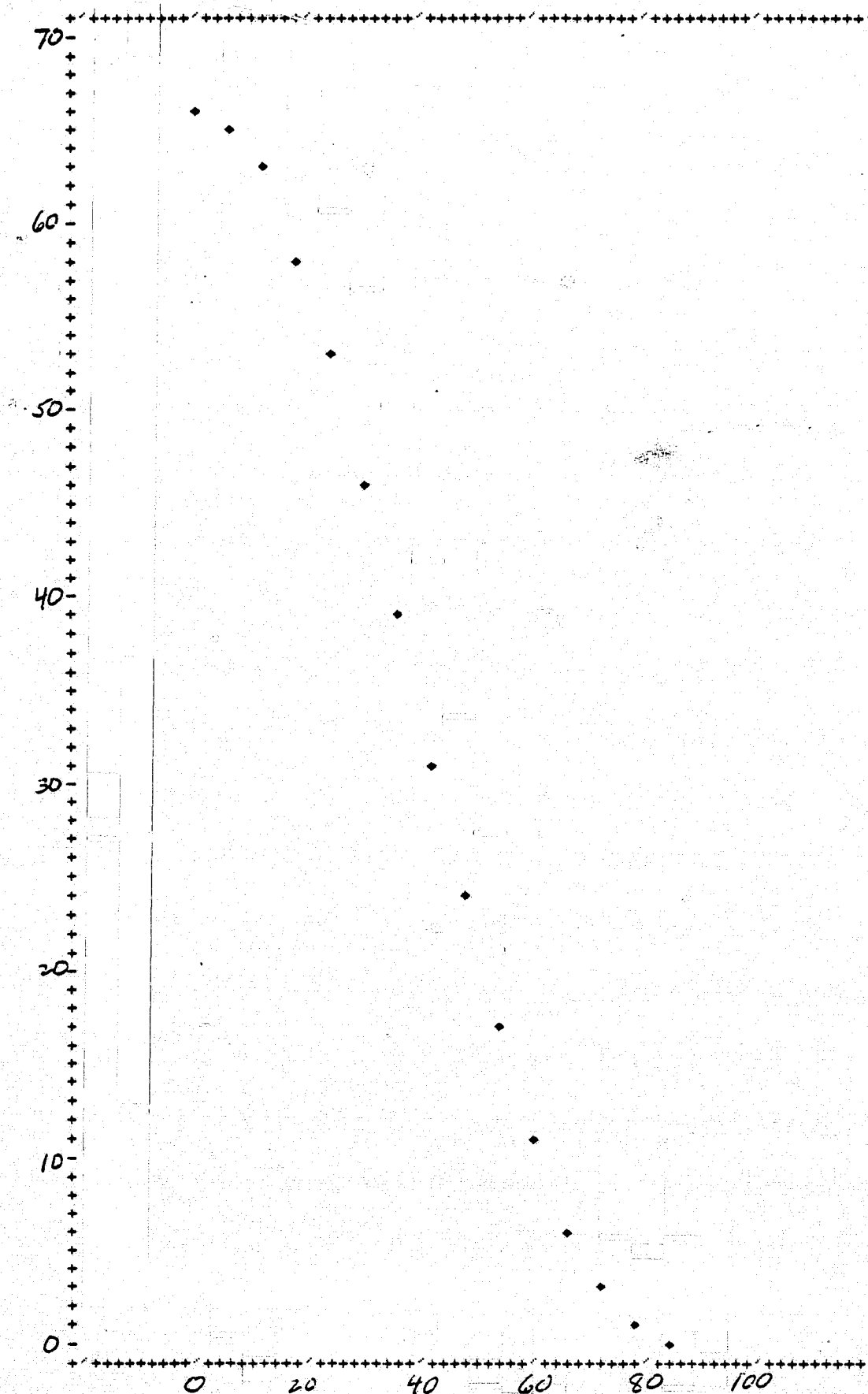


FIG. 8.4 EFFICIENCY VS. ANGLE OF INCIDENCE

TE WAVE, WAVELENGTH=	0.550 MICRONS	HALF-ANGLE OF TAPER=	0.500 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.000
DIELECTRIC CONSTANT=	10.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000	LOSS TANGENT=	0.000
CONDUCTIVITY=	0.000 MHQS/METER		

TABLE B.5

TE WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 1.000 DEGREES
 DIELECTRIC CONSTANT= 10.000 LOSS TANGENT= 0.000
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 0.000 MHOS/METER

IMPEDANCE OF MEDIUM= 0.11913E 03 + J 0.00000E 00 OHMS

FIRST 2 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.87582E 07	0.14325E 07	0.76513E 07	-0.16397E 07
2	0.25562E 08	0.47913E 07	0.53283E 07	-0.22986E 08

FIRST 2 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.17418E 08	0.29849E 07	0.38852E 07	-0.13382E 08
2	0.32587E 08	0.64420E 07	0.68582E 07	-0.30609E 08

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE	EFFICIENCY
0.00000E 00	0.90614E 02
0.60000E 01	0.89449E 02
0.12000E 02	0.86026E 02
0.18000E 02	0.80547E 02
0.24000E 02	0.73325E 02
0.30000E 02	0.64759E 02
0.36000E 02	0.55280E 02
0.42000E 02	0.45372E 02
0.48000E 02	0.35511E 02
0.54000E 02	0.26169E 02
0.60000E 02	0.17793E 02
0.66000E 02	0.10779E 02
0.72000E 02	0.54395E 01
0.78000E 02	0.19600E 01
0.84000E 02	0.30483E 00

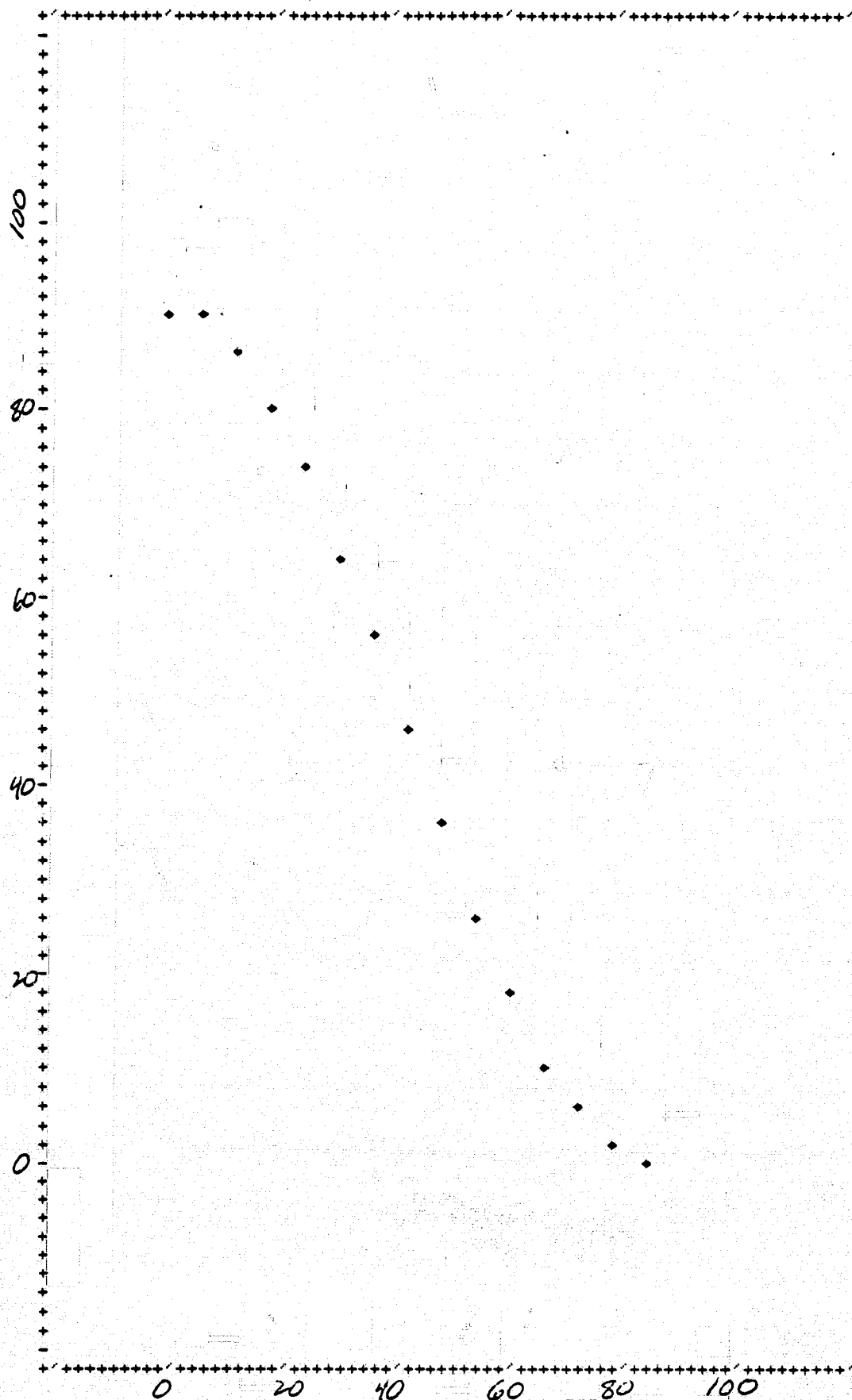


FIG. 8.5 EFFICIENCY VS. ANGLE OF INCIDENCE

TE WAVE, WAVELENGTH=	0.550 MICRONS	HALF-ANGLE OF TAPER=	1.000 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.000
DIELECTRIC CONSTANT=	10.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000		
CONDUCTIVITY=	0.000 MHQS/METER		

TABLE B.6

WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 2.000 DEGREES
 DIELECTRIC CONSTANT= 10.000 LOSS TANGENT= 0.000
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 0.000 MHOS/METER

IMPEDANCE OF MEDIUM= 0.11913E 03 + J 0.00000E 00 OHMS

FIRST 5 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.44721E 07	0.35747E 06	0.10519E 08	-0.15197E 06
2	0.13396E 08	0.10903E 07	0.20280E 07	-0.72015E 07
3	0.22268E 08	0.20422E 07	0.23744E 07	-0.19153E 08
4	0.30665E 08	0.33458E 07	0.36014E 07	-0.28489E 08
5	0.37627E 08	0.40599E 07	0.42583E 07	-0.35874E 08

FIRST 5 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.89398E 07	0.73222E 06	0.72075E 07	-0.90820E 06
2	0.17821E 08	0.15557E 07	0.20181E 07	-0.13738E 08
3	0.26539E 08	0.26350E 07	0.29153E 07	-0.23986E 08
4	0.34319E 08	0.39835E 07	0.42205E 07	-0.32392E 08
5	0.41305E 08	0.35925E 07	0.37371E 07	-0.39707E 08

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE	EFFICIENCY
0.00000E 00	0.97191E 02
0.60000E 01	0.96087E 02
0.12000E 02	0.92826E 02
0.18000E 02	0.87547E 02
0.24000E 02	0.80463E 02
0.30000E 02	0.71856E 02
0.36000E 02	0.62078E 02
0.42000E 02	0.51561E 02
0.48000E 02	0.40813E 02
0.54000E 02	0.30395E 02
0.60000E 02	0.20876E 02
0.66000E 02	0.12779E 02
0.72000E 02	0.65242E 01
0.78000E 02	0.23823E 01
0.84000E 02	0.37662E 00

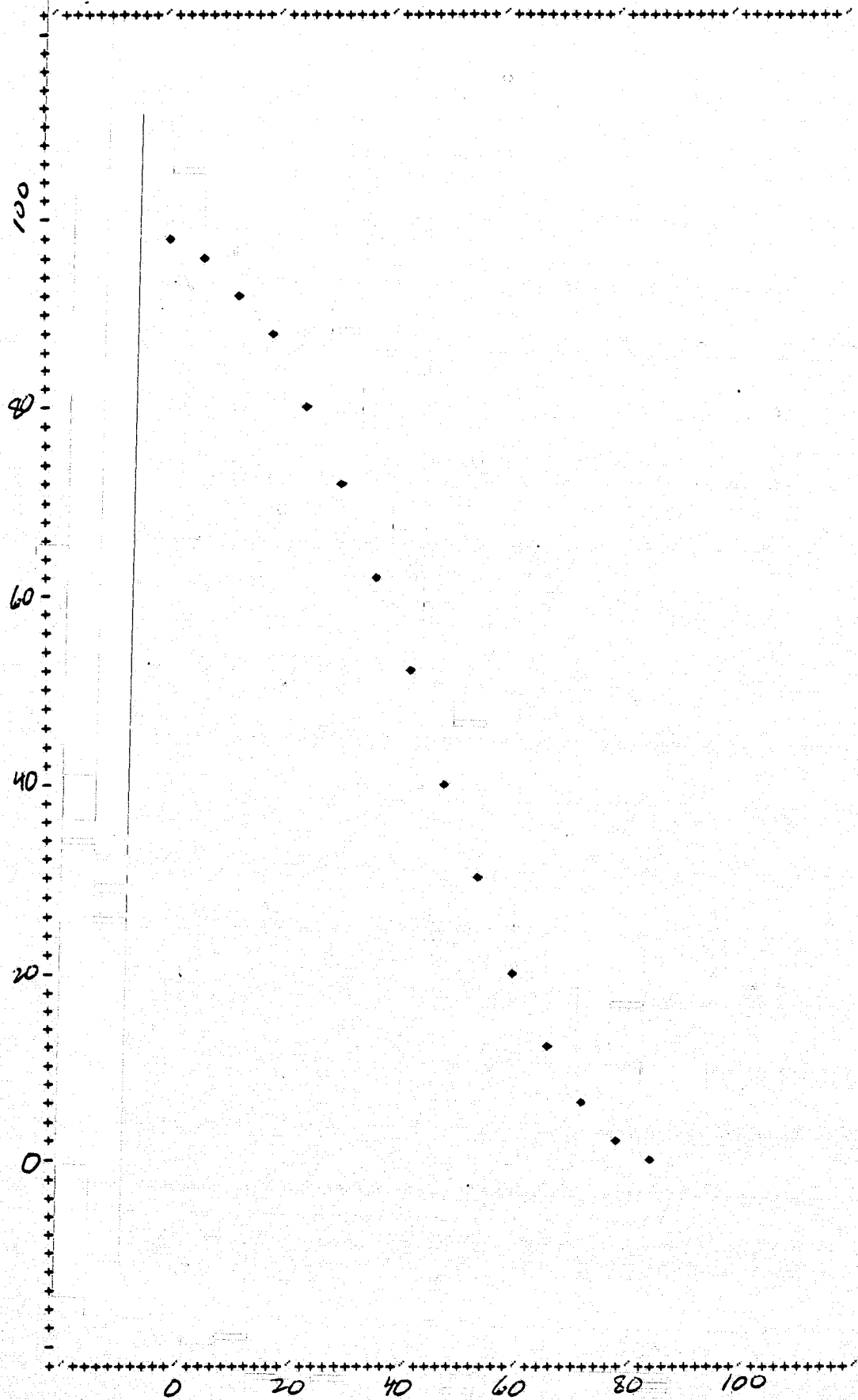


FIG. 8.6 EFFICIENCY VS. ANGLE OF INCIDENCE

TE WAVE, WAVELENGTH=	0.550 MICRONS	HALF-ANGLE OF TAPER=	2.000 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.000
DIELECTRIC CONSTANT=	10.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000	LOSS TANGENT=	0.000
CONDUCTIVITY=	0.000 MHQS/METER		

TABLE 8.7

TE WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 5.000 DEGREES
 DIELECTRIC CONSTANT= 10.000 LOSS TANGENT= 0.000
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 0.000 MHQS/METER

IMPEDANCE OF MEDIUM= 0.11913E 03 + J 0.00000E 00 OHMS

FIRST 7 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.18005E 07	0.57184E 05	0.11281E 08	-0.91264E 04
2	0.54012E 07	0.17351E 06	0.10068E 08	-0.93078E 05
3	0.90014E 07	0.29536E 06	0.70506E 07	-0.37708E 06
4	0.12600E 08	0.42804E 06	0.10002E 07	-0.53925E 07
5	0.16197E 08	0.55116E 06	0.77662E 06	-0.11495E 08
6	0.19786E 08	0.71012E 06	0.86931E 06	-0.16163E 08
7	0.23384E 08	0.88265E 06	0.10113E 07	-0.20409E 08

FIRST 7 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.36009E 07	0.11437E 06	0.10842E 08	-0.37984E 05
2	0.72014E 07	0.23345E 06	0.88734E 07	-0.18947E 06
3	0.10801E 08	0.35993E 06	0.38706E 07	-0.10044E 07
4	0.14399E 08	0.47585E 06	0.77978E 06	-0.87867E 07
5	0.17993E 08	0.63163E 06	0.81700E 06	-0.13911E 08
6	0.21574E 08	0.79261E 06	0.93401E 06	-0.18308E 08
7	0.25157E 08	0.98611E 06	0.11065E 07	-0.22419E 08

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE EFFICIENCY

0.00000E 00	0.99552E 02
0.60000E 01	0.98400E 02
0.12000E 02	0.95156E 02
0.18000E 02	0.89970E 02
0.24000E 02	0.82895E 02
0.30000E 02	0.74369E 02
0.36000E 02	0.64839E 02
0.42000E 02	0.54548E 02
0.48000E 02	0.43905E 02
0.54000E 02	0.33503E 02
0.60000E 02	0.23860E 02
0.66000E 02	0.15368E 02
0.72000E 02	0.84017E 01
0.78000E 02	0.33637E 01
0.84000E 02	0.60461E 00

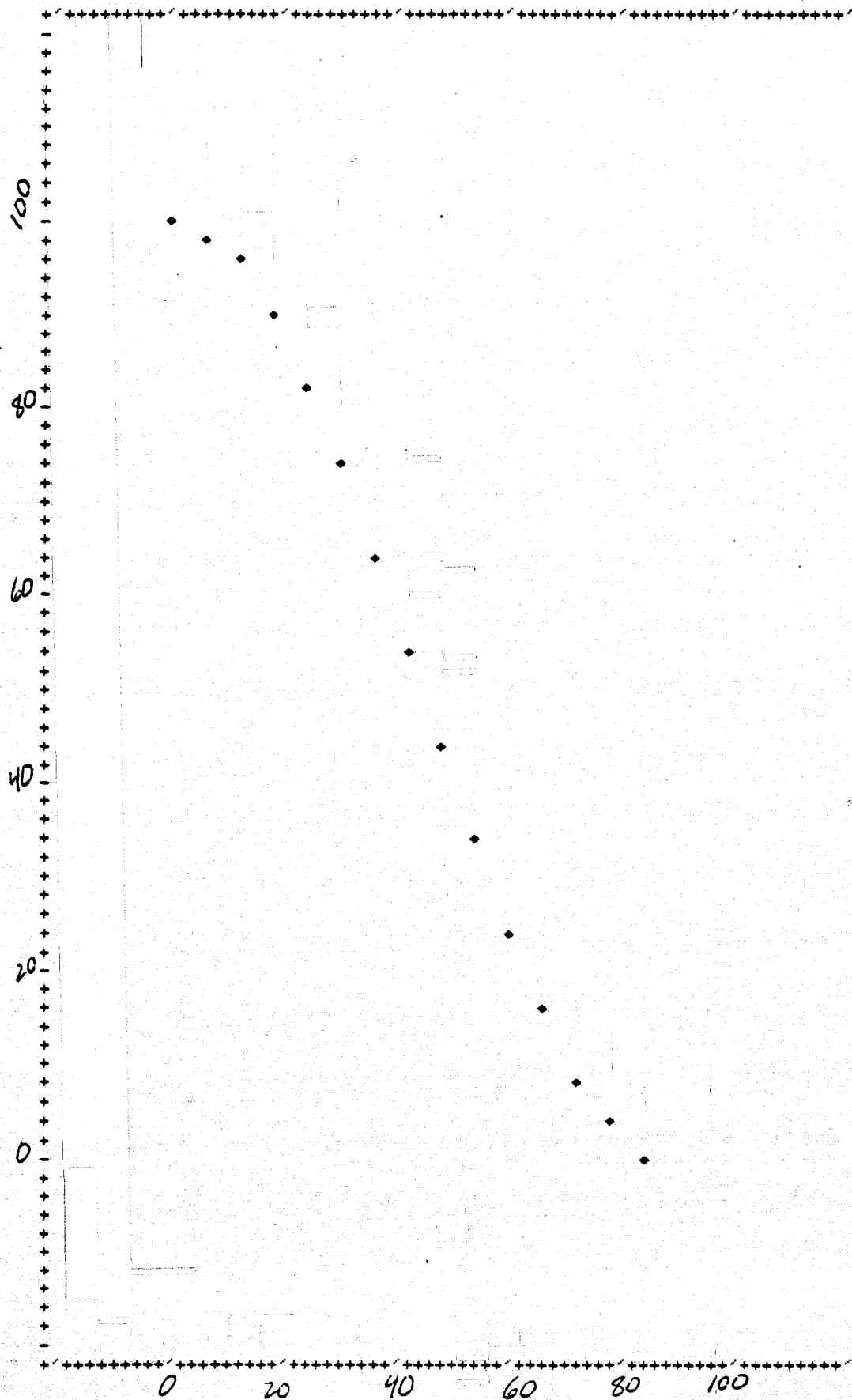


FIG. 8.7 EFFICIENCY VS. ANGLE OF INCIDENCE

TE WAVE, WAVELENGTH=	0.550 MICRONS	HALF-ANGLE OF TAPER=	5.000 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.000
DIELECTRIC CONSTANT=	10.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000	LOSS TANGENT=	0.000
CONDUCTIVITY=	0.000 MHQS/METER		

TABLE B.8

TM WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 0.125 DEGREES
 DIELECTRIC CONSTANT= 10.000 LOSS TANGENT= 0.000
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 0.000 MHOS/METER

IMPEDANCE OF MEDIUM= 0.11913E 03 + J 0.00000E 00 OHMS

FIRST 1 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.92150E 07	0.89698E 07	0.12922E 08	-0.63968E 07

FIRST 1 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.72000E 08	0.22998E 07	0.23293E 07	-0.71089E 08

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE	EFFICIENCY
0.00000E 00	0.93188E 02
0.60000E 01	0.92106E 02
0.12000E 02	0.88905E 02
0.18000E 02	0.83712E 02
0.24000E 02	0.76743E 02
0.30000E 02	0.68293E 02
0.36000E 02	0.58734E 02
0.42000E 02	0.48509E 02
0.48000E 02	0.38116E 02
0.54000E 02	0.28097E 02
0.60000E 02	0.19003E 02
0.66000E 02	0.11357E 02
0.72000E 02	0.55873E 01
0.78000E 02	0.19286E 01
0.84000E 02	0.28052E 00

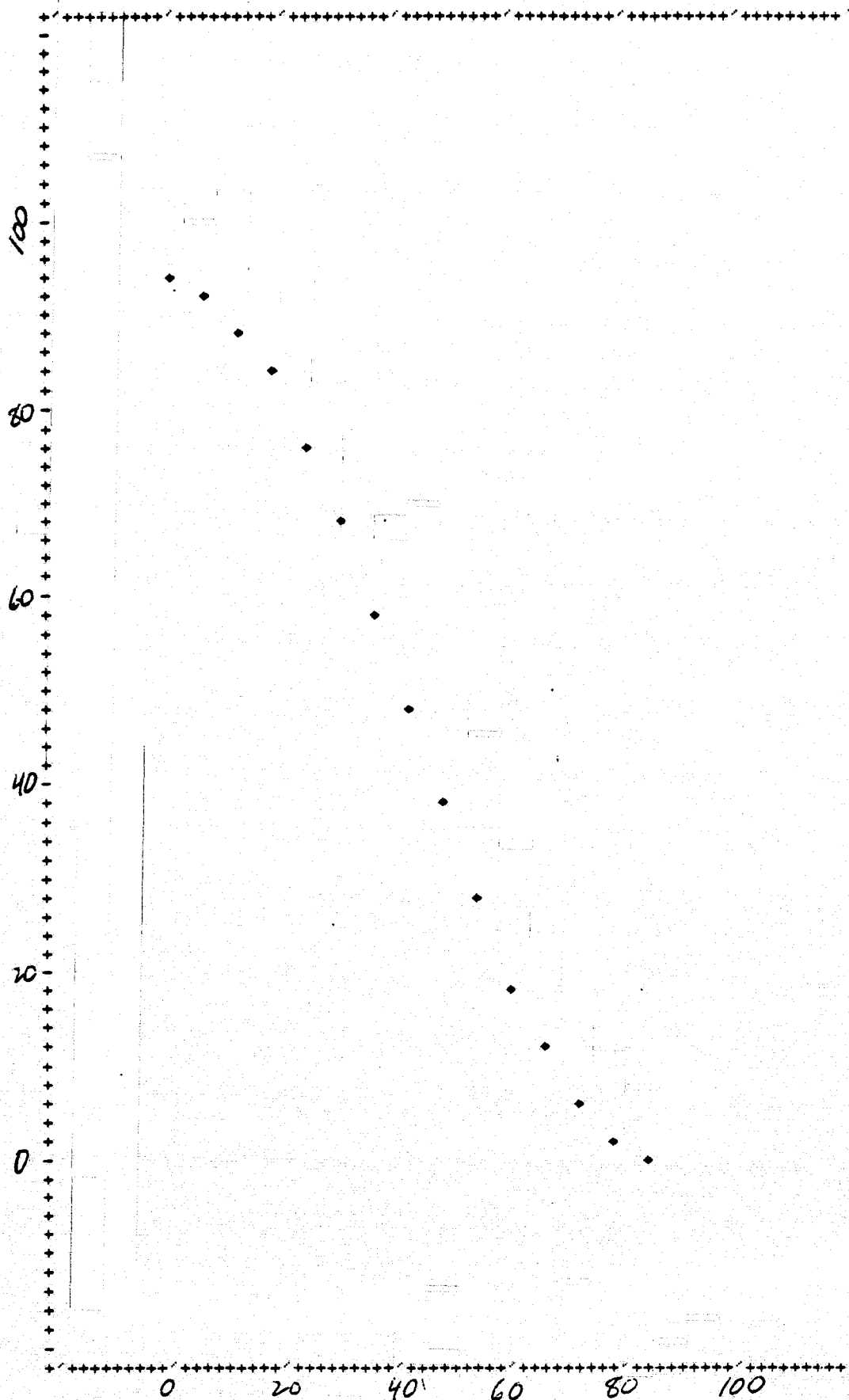


FIG. 8.8 EFFICIENCY VS. ANGLE OF INCIDENCE

TM WAVE, WAVELENGTH=	0.550 MICRONS	HALF-ANGLE OF TAPER=	0.125 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.000
DIELECTRIC CONSTANT=	10.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000	CONDUCTIVITY=	0.000 MHOS/METER

TABLE B.9

TM WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 0.250 DEGREES
 DIELECTRIC CONSTANT= 10.000 LOSS TANGENT= 0.000
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 0.000 MHOS/METER

IMPEDANCE OF MEDIUM= 0.11913E 03 + J 0.00000E 00 OHMS

FIRST 1 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.65883E 07	0.62417E 07	0.11760E 08	-0.34969E 07

FIRST 1 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.36147E 08	0.22926E 07	0.24159E 07	-0.34303E 08

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE	EFFICIENCY
0.00000E 00	0.97755E 02
0.60000E 01	0.96662E 02
0.12000E 02	0.93426E 02
0.18000E 02	0.88168E 02
0.24000E 02	0.81090E 02
0.30000E 02	0.72475E 02
0.36000E 02	0.62679E 02
0.42000E 02	0.52130E 02
0.48000E 02	0.41317E 02
0.54000E 02	0.30780E 02
0.60000E 02	0.21088E 02
0.66000E 02	0.12803E 02
0.72000E 02	0.64200E 01
0.78000E 02	0.22682E 01
0.84000E 02	0.33939E 00

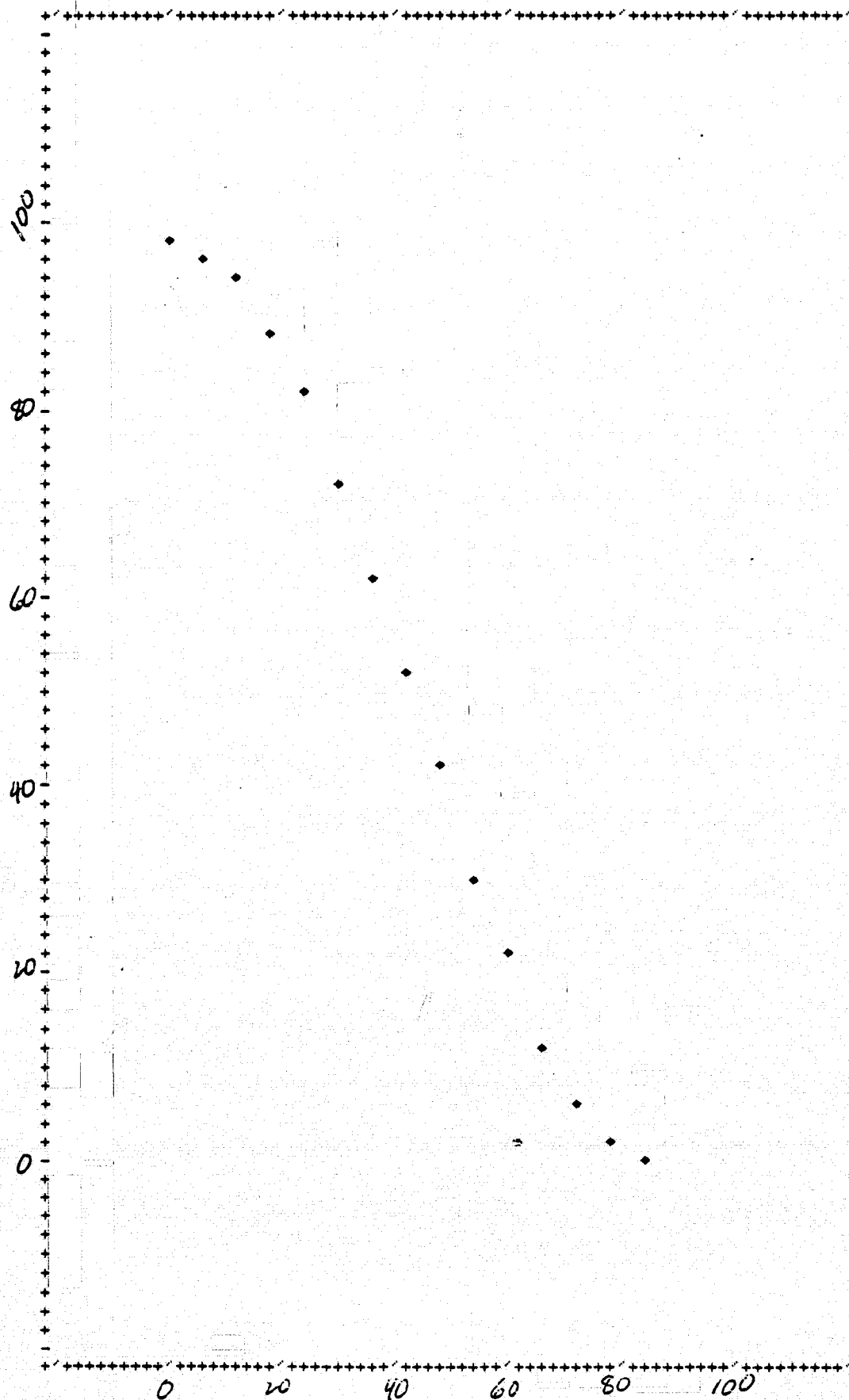


FIG. B.9 EFFICIENCY VS. ANGLE OF INCIDENCE

TM WAVE, WAVELENGTH=	0.550 MICRONS	HALF-ANGLE OF TAPER=	0.250 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.000
DIELECTRIC CONSTANT=	10.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000		
CONDUCTIVITY=	0.000 MHOS/METER		

TABLE B.10

TM WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 0.500 DEGREES
 DIELECTRIC CONSTANT= 10.000 LOSS TANGENT= 0.000
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 0.000 MHOS/METER

IMPEDANCE OF MEDIUM= 0.11913E 03 + J 0.00000E 00 OHMS

FIRST 1 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.47968E 07	0.43067E 07	0.11372E 08	-0.18173E 07

FIRST 1 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.18293E 08	0.22703E 07	0.28644E 07	-0.14398E 08

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE	EFFICIENCY
0.00000E 00	0.99368E 02
0.60000E 01	0.98262E 02
0.12000E 02	0.94985E 02
0.18000E 02	0.89662E 02
0.24000E 02	0.82499E 02
0.30000E 02	0.73782E 02
0.36000E 02	0.63868E 02
0.42000E 02	0.53190E 02
0.48000E 02	0.42236E 02
0.54000E 02	0.31547E 02
0.60000E 02	0.21690E 02
0.66000E 02	0.13231E 02
0.72000E 02	0.66774E 01
0.78000E 02	0.23794E 01
0.84000E 02	0.36012E 00

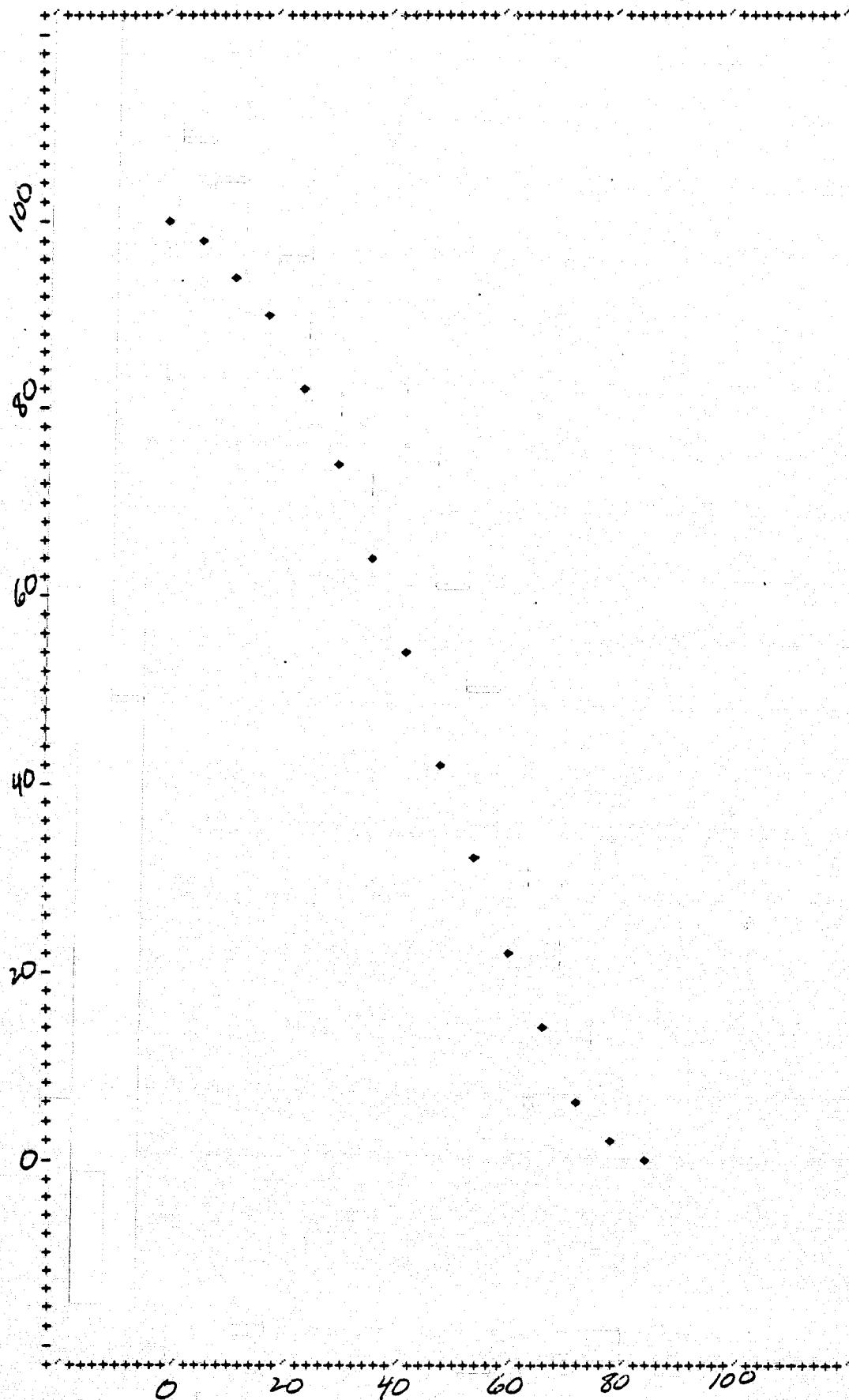


FIG. 8.10 EFFICIENCY VS. ANGLE OF INCIDENCE

TM WAVE, WAVELENGTH=	0.550 MICRONS	HALF-ANGLE OF TAPER=	0.500 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.000
DIELECTRIC CONSTANT=	10.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000	CONDUCTIVITY=	0.000 MHQS/METER

TABLE B.11

TM WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 5.000 DEGREES
 DIELECTRIC CONSTANT= 10.000 LOSS TANGENT= 0.000
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 0.000 MHOS/METER

IMPEDANCE OF MEDIUM= 0.11913E 03 + J 0.00000E 00 OHMS

FIRST 7 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.15897E 07	0.52615E 06	0.11325E 08	-0.73855E 05
2	0.41581E 07	0.10758E 07	0.10703E 08	-0.41795E 06
3	0.72674E 07	0.61766E 06	0.88505E 07	-0.50718E 06
4	0.10831E 08	0.39581E 06	0.38225E 07	-0.11215E 07
5	0.14425E 08	0.29312E 06	0.47963E 06	-0.88155E 07
6	0.18026E 08	0.23471E 06	0.30340E 06	-0.13945E 08
7	0.21629E 08	0.19437E 06	0.22890E 06	-0.18367E 08

FIRST 7 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.29592E 07	0.98911E 06	0.11081E 08	-0.26414E 06
2	0.55871E 07	0.83857E 06	0.10011E 08	-0.46801E 06
3	0.90449E 07	0.48353E 06	0.70228E 07	-0.62275E 06
4	0.12626E 08	0.33824E 06	0.78739E 06	-0.54239E 07
5	0.16225E 08	0.26206E 06	0.36895E 06	-0.11524E 08
6	0.19828E 08	0.21261E 06	0.26012E 06	-0.16206E 08
7	0.23431E 08	0.17904E 06	0.20506E 06	-0.20458E 08

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE	EFFICIENCY
0.00000E 00	0.99990E 02
0.60000E 01	0.98891E 02
0.12000E 02	0.95642E 02
0.18000E 02	0.90387E 02
0.24000E 02	0.83339E 02
0.30000E 02	0.74804E 02
0.36000E 02	0.65180E 02
0.42000E 02	0.54849E 02
0.48000E 02	0.44205E 02
0.54000E 02	0.33762E 02
0.60000E 02	0.24046E 02
0.66000E 02	0.15490E 02
0.72000E 02	0.84713E 01
0.78000E 02	0.33867E 01
0.84000E 02	0.60463E 00

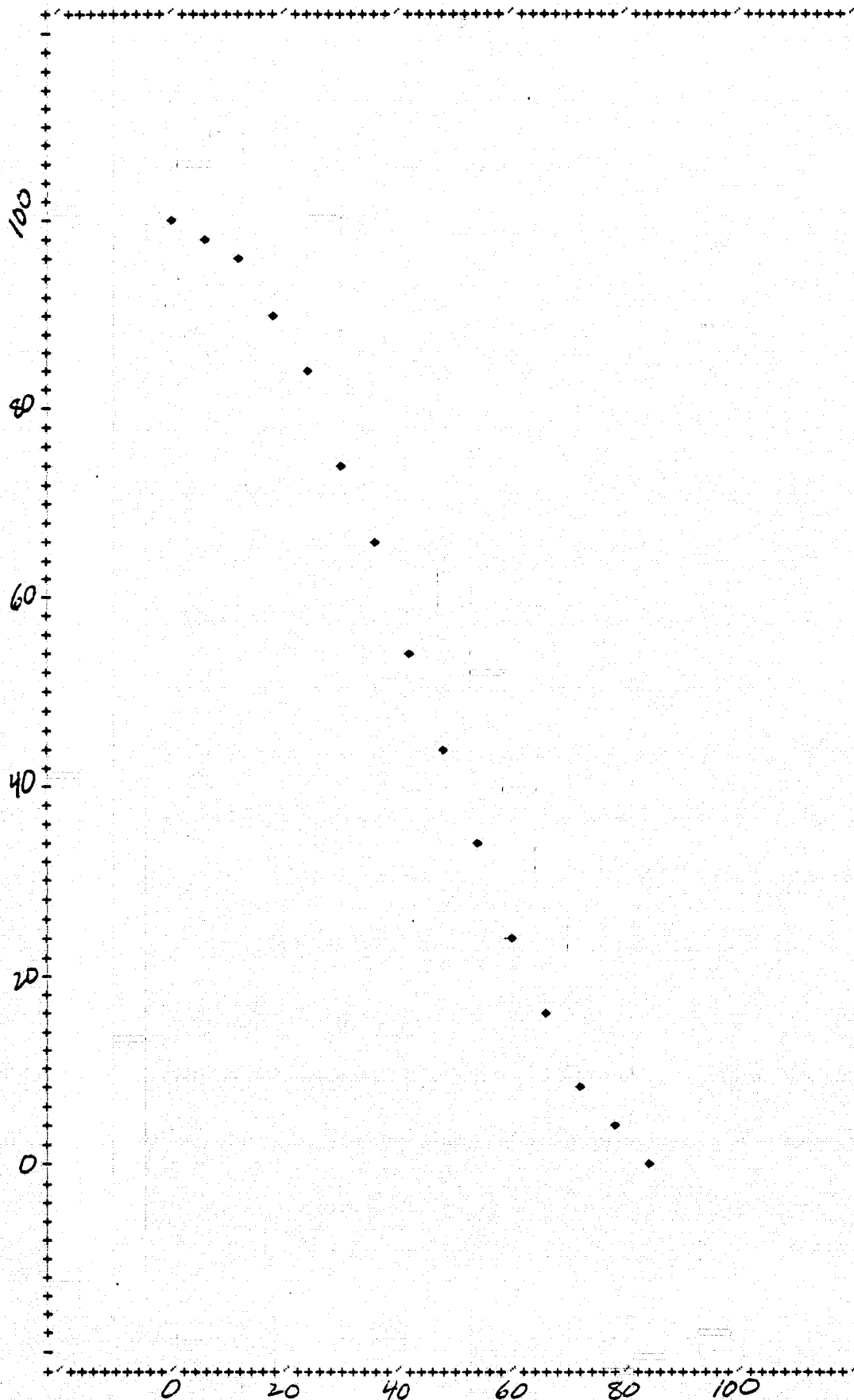


FIG. 8.11 EFFICIENCY VS. ANGLE OF INCIDENCE

TM WAVE, WAVELENGTH=	0.550 MICRONS	HALF-ANGLE OF TAPER=	5.000 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.000
DIELECTRIC CONSTANT=	10.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000		
CONDUCTIVITY=	0.000 MHOS/METER		

TABLE B.12

TE WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 5.000 DEGREES
 DIELECTRIC CONSTANT= 100.000 LOSS TANGENT= 0.000
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 0.000 MHOS/METER

IMPEDANCE OF MEDIUM= 0.37673E 02 + J 0.00000E 00 OHMS

FIRST 7 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.18021E 07	0.18100E 05	0.11281E 08	-0.28914E 04
2	0.54063E 07	0.54299E 05	0.10064E 08	-0.29169E 05
3	0.90105E 07	0.90498E 05	0.70242E 07	-0.11609E 06
4	0.12615E 08	0.12748E 06	0.30018E 06	-0.53570E 07
5	0.16219E 08	0.16457E 06	0.23182E 06	-0.11514E 08
6	0.19823E 08	0.20218E 06	0.24739E 06	-0.16201E 08
7	0.23427E 08	0.24046E 06	0.27542E 06	-0.20453E 08

FIRST 7 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.36042E 07	0.36199E 05	0.10841E 08	-0.12035E 05
2	0.72084E 07	0.72398E 05	0.88631E 07	-0.58882E 05
3	0.10813E 08	0.10860E 06	0.37022E 07	-0.31716E 06
4	0.14417E 08	0.14597E 06	0.23924E 06	-0.87962E 07
5	0.18021E 08	0.18330E 06	0.23700E 06	-0.13938E 08
6	0.21625E 08	0.22123E 06	0.26055E 06	-0.18362E 08
7	0.25229E 08	0.25989E 06	0.29148E 06	-0.22495E 08

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE EFFICIENCY

0.00000E 00	0.99738E 02
0.60000E 01	0.98561E 02
0.12000E 02	0.95319E 02
0.18000E 02	0.90168E 02
0.24000E 02	0.83075E 02
0.30000E 02	0.74540E 02
0.36000E 02	0.65069E 02
0.42000E 02	0.54805E 02
0.48000E 02	0.44121E 02
0.54000E 02	0.33713E 02
0.60000E 02	0.24160E 02
0.66000E 02	0.15786E 02
0.72000E 02	0.88367E 01
0.78000E 02	0.36555E 01
0.84000E 02	0.68520E 00

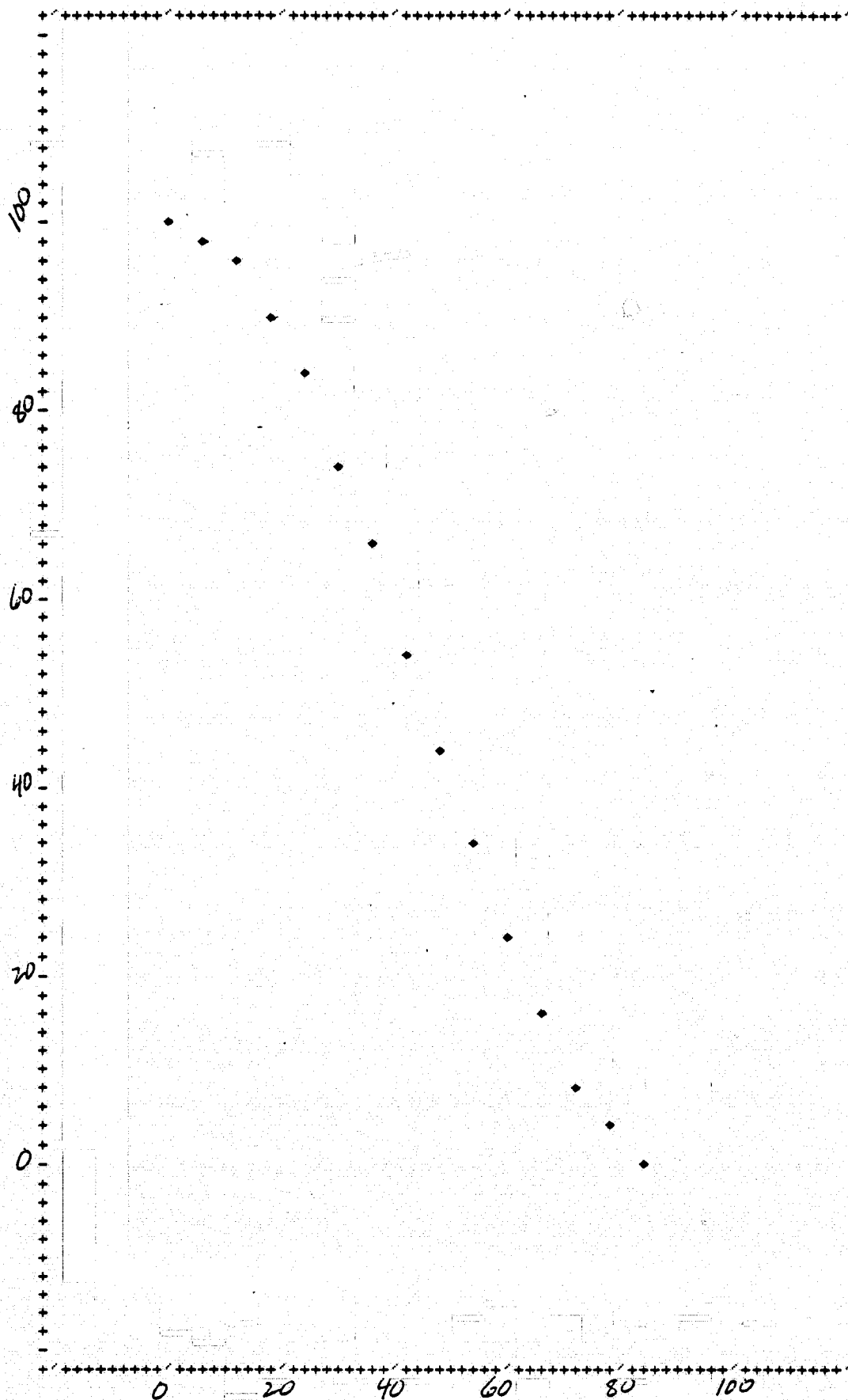


FIG. 8.12 EFFICIENCY VS. ANGLE OF INCIDENCE

TE WAVE, WAVELENGTH=	0.550 MICRONS	HALF-ANGLE OF TAPER=	5.000 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.000
DIELECTRIC CONSTANT=	100.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000	CONDUCTIVITY=	0.000 MHQS/METER

TABLE B.13

WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 5.000 DEGREES
 DIELECTRIC CONSTANT= 100.000 LOSS TANGENT= 0.000
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 0.000 MHQS/METER

IMPEDANCE OF MEDIUM= 0.37673E 02 + J 0.00000E 00 OHMS

FIRST 5 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.92096E 06	0.65045E 06	0.11405E 08	-0.52522E 05
2	0.36472E 07	0.36905E 06	0.10833E 08	-0.12425E 06
3	0.72140E 07	0.18391E 06	0.88613E 07	-0.14972E 06
4	0.10815E 08	0.12186E 06	0.36990E 07	-0.35631E 06
5	0.14418E 08	0.90909E 05	0.14899E 06	-0.87974E 07

FIRST 5 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.20404E 07	0.62296E 06	0.11258E 08	-0.11291E 06
2	0.54186E 07	0.24695E 06	0.10061E 08	-0.13300E 06
3	0.90139E 07	0.14656E 06	0.70224E 07	-0.18812E 06
4	0.12616E 08	0.10390E 06	0.24465E 06	-0.53577E 07
5	0.16221E 08	0.80808E 05	0.11383E 06	-0.11515E 08

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE	EFFICIENCY
0.00000E 00	0.99999E 02
0.60000E 01	0.98903E 02
0.12000E 02	0.95655E 02
0.18000E 02	0.90399E 02
0.24000E 02	0.83348E 02
0.30000E 02	0.74811E 02
0.36000E 02	0.65209E 02
0.42000E 02	0.54893E 02
0.48000E 02	0.44228E 02
0.54000E 02	0.33773E 02
0.60000E 02	0.24102E 02
0.66000E 02	0.15621E 02
0.72000E 02	0.86349E 01
0.78000E 02	0.35058E 01
0.84000E 02	0.63964E 00

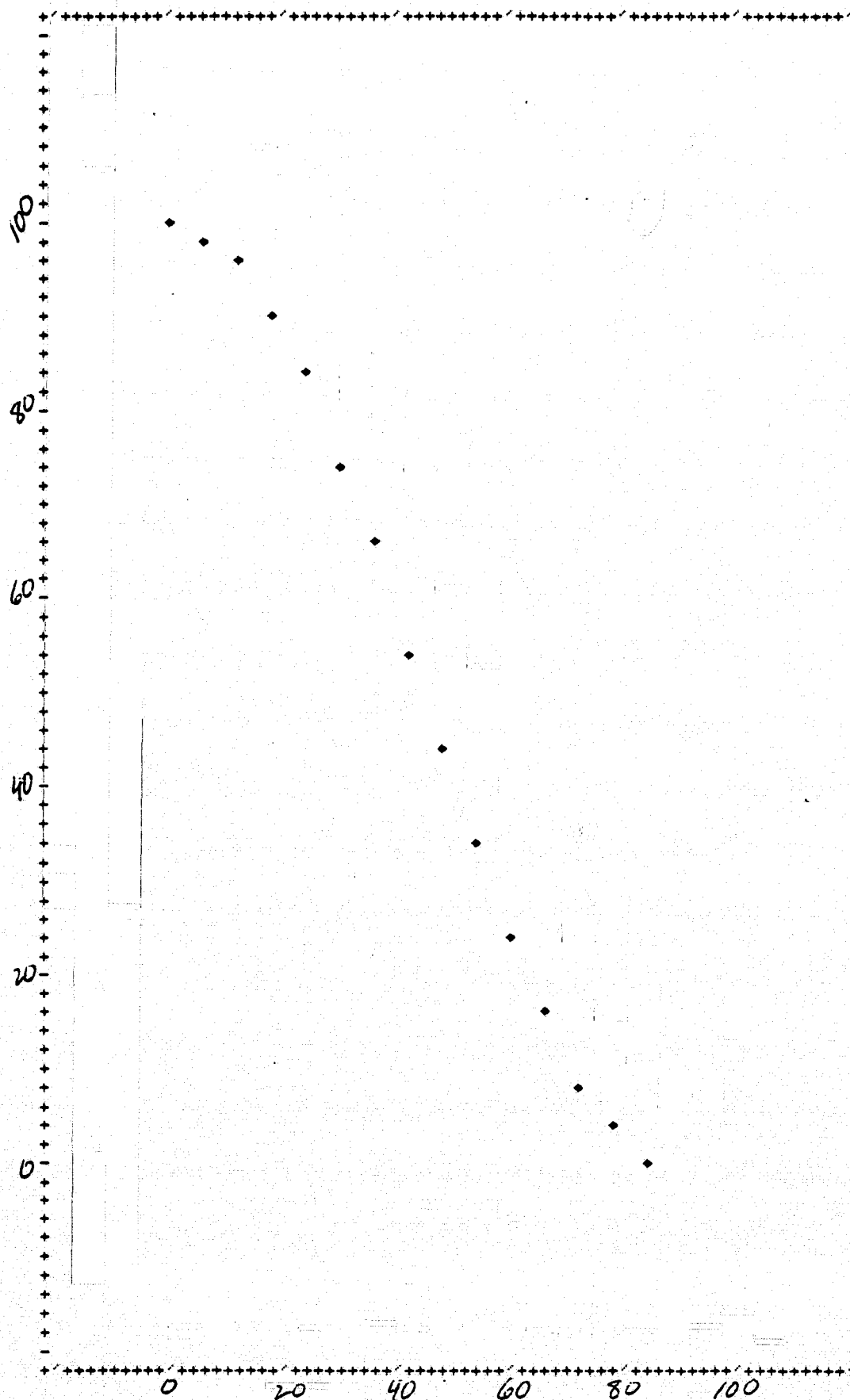


FIG. 8.13 EFFICIENCY VS. ANGLE OF INCIDENCE

TM WAVE, WAVELENGTH=	0.550 MICRONS	HALF-ANGLE OF TAPER=	5.000 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.000
DIELECTRIC CONSTANT=	100.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000		
CONDUCTIVITY=	0.000 MHOS/METER		

TABLE 8.14

WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 5.000 DEGREES
 DIELECTRIC CONSTANT= 1000.000 LOSS TANGENT= 0.000
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 0.000 MHOS/METER

IMPEDANCE OF MEDIUM= 0.11913E 02 + J 0.00000E 00 OHMS

FIRST 4 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.48015E 06	0.43100E 06	0.11422E 08	-0.18118E 05
2	0.36083E 07	0.11533E 06	0.10840E 08	-0.38392E 05
3	0.72091E 07	0.57496E 05	0.88623E 07	-0.46771E 05
4	0.10814E 08	0.38331E 05	0.36858E 07	-0.11246E 06

FIRST 4 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.18316E 07	0.22703E 06	0.11279E 08	-0.36869E 05
2	0.54069E 07	0.76661E 05	0.10064E 08	-0.41187E 05
3	0.90114E 07	0.45997E 05	0.70219E 07	-0.59029E 05
4	0.12616E 08	0.32855E 05	0.77424E 05	-0.53536E 07

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE	EFFICIENCY
0.00000E 00	0.99999E 02
0.60000E 01	0.98904E 02
0.12000E 02	0.95656E 02
0.18000E 02	0.90400E 02
0.24000E 02	0.83347E 02
0.30000E 02	0.74803E 02
0.36000E 02	0.65220E 02
0.42000E 02	0.54909E 02
0.48000E 02	0.44202E 02
0.54000E 02	0.33730E 02
0.60000E 02	0.24101E 02
0.66000E 02	0.15680E 02
0.72000E 02	0.87107E 01
0.78000E 02	0.35504E 01
0.84000E 02	0.64931E 00

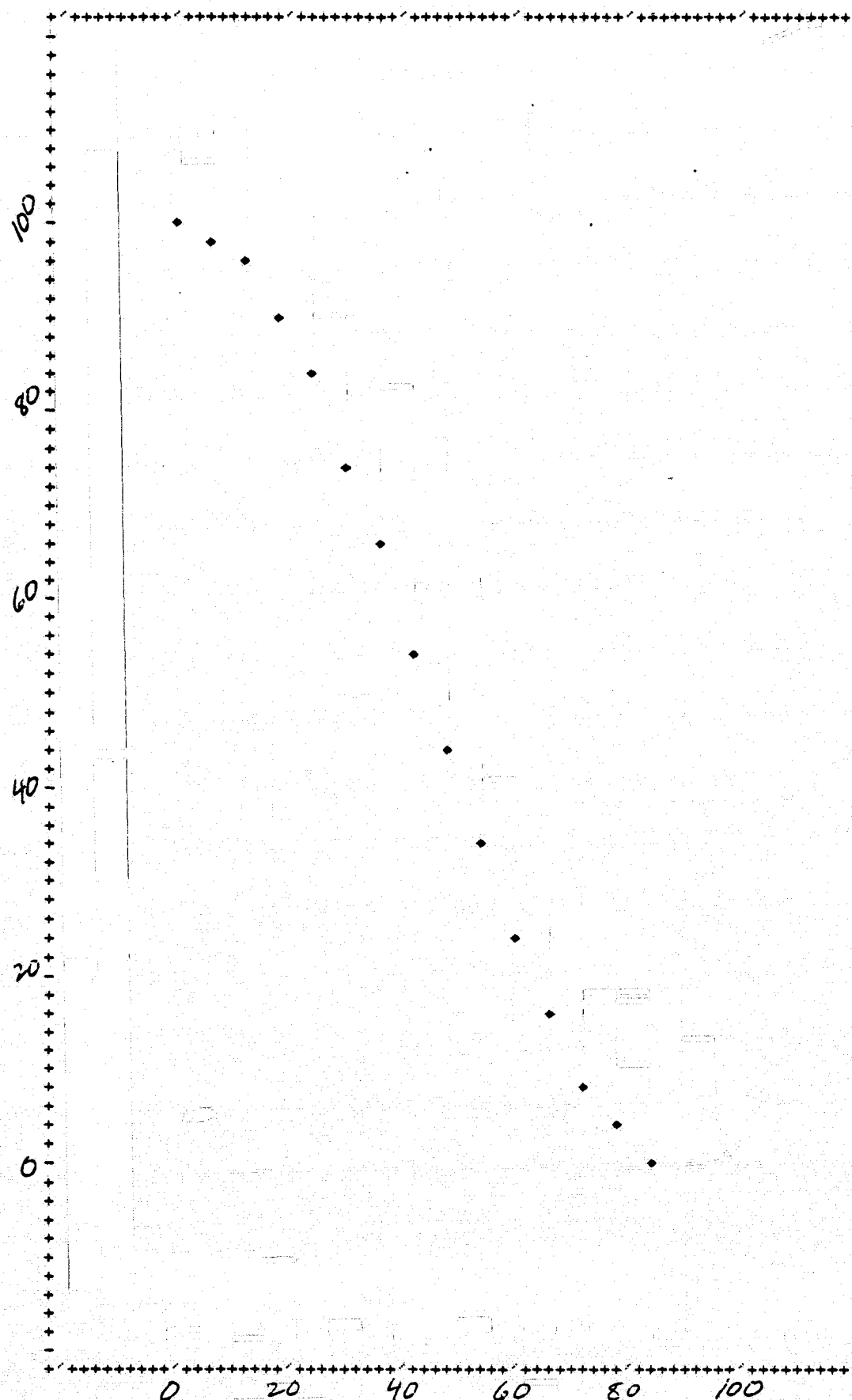


FIG. 8.14 EFFICIENCY VS. ANGLE OF INCIDENCE

TM WAVE, WAVELENGTH=	0.550 MICRONS	HALF-ANGLE OF TAPER=	5.000 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.000
DIELECTRIC CONSTANT=	1000.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000	CONDUCTIVITY=	0.000 MHOS/METER

TABLE B.15

WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 5.000 DEGREES
 DIELECTRIC CONSTANT= 1000.000 LOSS TANGENT= 0.000
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 0.000 MHOS/METER

IMPEDANCE OF MEDIUM= 0.11913E 02 + J 0.00000E 00 OHMS

FIRST 4 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.18023E 07	0.57241E 04	0.11281E 08	-0.91449E 03
2	0.54068E 07	0.17172E 05	0.10064E 08	-0.92261E 04
3	0.90113E 07	0.28620E 05	0.70218E 07	-0.36730E 05
4	0.12616E 08	0.40069E 05	0.94423E 05	-0.53536E 07

FIRST 4 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.36045E 07	0.11448E 05	0.10840E 08	-0.38066E 04
2	0.72091E 07	0.22896E 05	0.88621E 07	-0.18625E 05
3	0.10814E 08	0.34345E 05	0.36857E 07	-0.10076E 06
4	0.14418E 08	0.45793E 05	0.75057E 05	-0.87966E 07

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE	EFFICIENCY
0.00000E 00	0.99817E 02
0.60000E 01	0.98628E 02
0.12000E 02	0.95386E 02
0.18000E 02	0.90252E 02
0.24000E 02	0.83149E 02
0.30000E 02	0.74610E 02
0.36000E 02	0.65165E 02
0.42000E 02	0.54912E 02
0.48000E 02	0.44206E 02
0.54000E 02	0.33793E 02
0.60000E 02	0.24278E 02
0.66000E 02	0.15953E 02
0.72000E 02	0.90083E 01
0.78000E 02	0.37662E 01
0.84000E 02	0.71332E 00

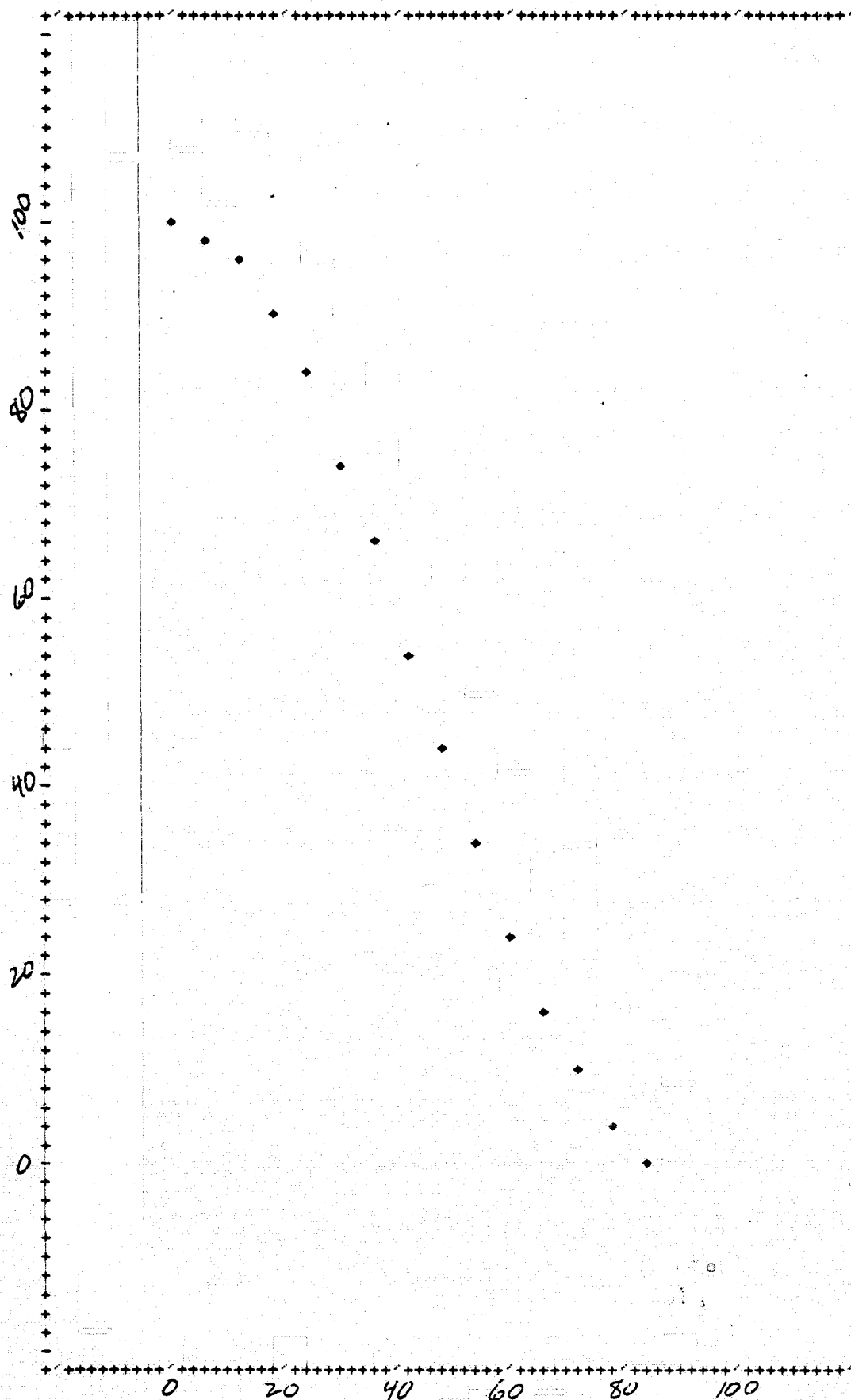


FIG. 8.15 EFFICIENCY VS. ANGLE OF INCIDENCE

TE WAVE, WAVELENGTH=	0.550 MICRONS	
LENGTH OF TAPER=	10.000 MICRONS	HALF-ANGLE OF TAPER= 5.000 DEGREES
DIELECTRIC CONSTANT=	1000.000	LOSS TANGENT= 0.000
RELATIVE PERMEABILITY=	1.000	LOSS TANGENT= 0.000
CONDUCTIVITY=	0.000 MHOS/METER	

TABLE B.16

WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 5.000 DEGREES
 DIELECTRIC CONSTANT= 10.000 LOSS TANGENT= 0.100
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 0.000 MHOS/METER

IMPEDANCE OF MEDIUM= 0.11869E 03 + J 0.59197E 01 OHMS

FIRST 5 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.17977E 07	0.56792E 05	0.11282E 08	-0.90493E 04
2	0.53925E 07	0.17226E 06	0.10073E 08	-0.92215E 05
3	0.89859E 07	0.29302E 06	0.70700E 07	-0.37242E 06
4	0.12576E 08	0.42404E 06	0.99938E 06	-0.53362E 07
5	0.16160E 08	0.54443E 06	0.76887E 06	-0.11443E 08

FIRST 5 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.35953E 07	0.11358E 06	0.10844E 08	-0.37658E 05
2	0.71894E 07	0.23170E 06	0.88830E 07	-0.18753E 06
3	0.10782E 08	0.35686E 06	0.39186E 07	-0.98186E 06
4	0.14369E 08	0.47085E 06	0.77431E 06	-0.87379E 07
5	0.17948E 08	0.62227E 06	0.80626E 06	-0.13852E 08

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE	EFFICIENCY
0.00000E 00	0.99648E 02
0.60000E 01	0.98492E 02
0.12000E 02	0.95249E 02
0.18000E 02	0.90067E 02
0.24000E 02	0.82989E 02
0.30000E 02	0.74462E 02
0.36000E 02	0.64937E 02
0.42000E 02	0.54644E 02
0.48000E 02	0.43994E 02
0.54000E 02	0.33592E 02
0.60000E 02	0.23947E 02
0.66000E 02	0.15441E 02
0.72000E 02	0.84472E 01
0.78000E 02	0.33812E 01
0.84000E 02	0.60704E 00

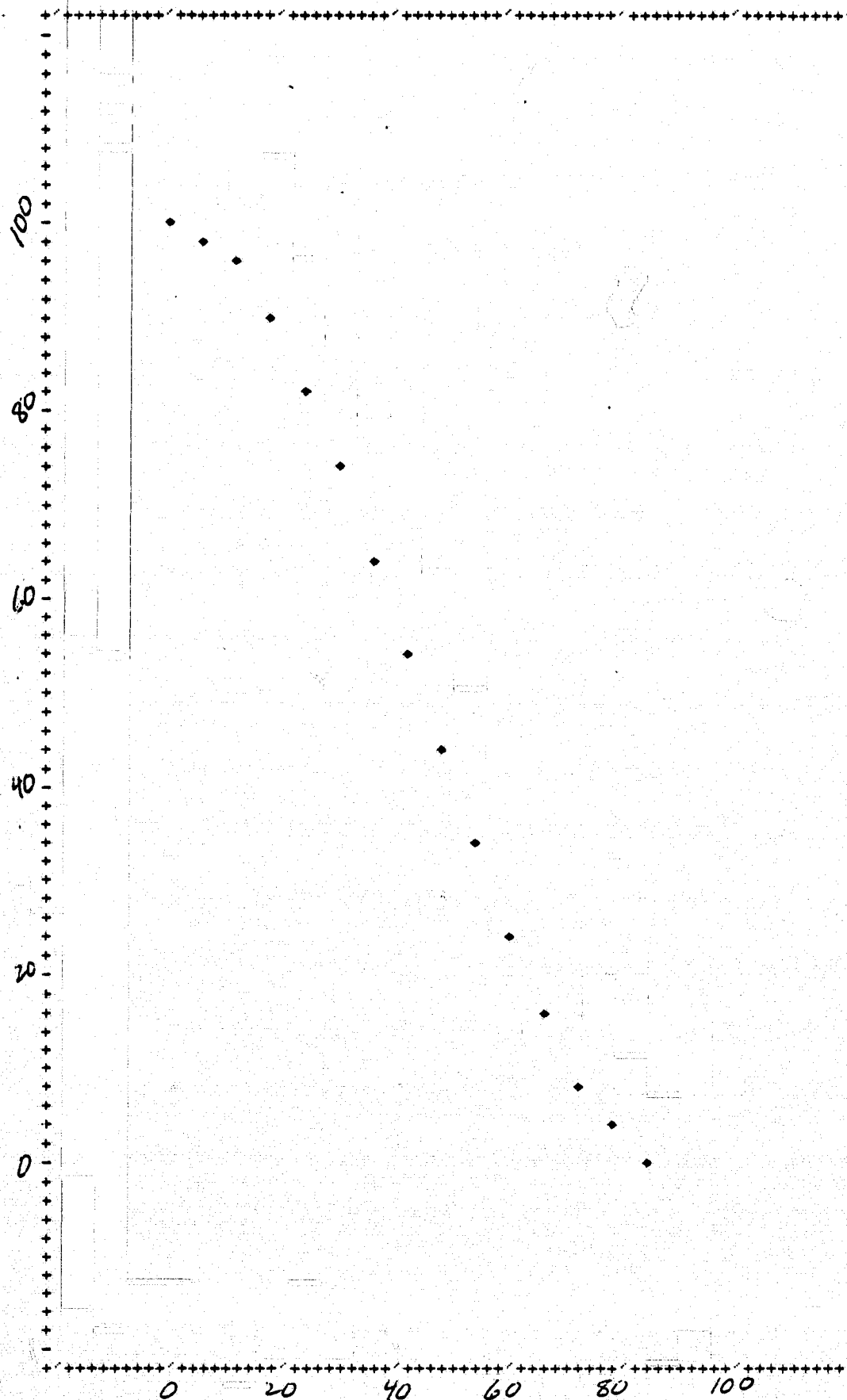


FIG. 8.16 EFFICIENCY VS. ANGLE OF INCIDENCE

TE WAVE. WAVELENGTH=	0.550 MICRONS	HALF-ANGLE OF TAPER=	5.000 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.100
DIELECTRIC CONSTANT=	10.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000		
CONDUCTIVITY=	0.000 MHQS/METER		

TABLE B.17

TM WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 5.000 DEGREES
 DIELECTRIC CONSTANT= 10.000 LOSS TANGENT= 0.100
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 0.000 MHQS/METER

IMPEDANCE OF MEDIUM= 0.11369E 03 + J 0.59197E 01 OHMS

FIRST 5 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.16117E 07	0.55045E 06	0.11323E 03	-0.78345E 05
2	0.41160E 07	0.11315E 07	0.10725E 03	-0.43423E 06
3	0.72359E 07	0.62382E 06	0.88767E 07	-0.50851E 06
4	0.10808E 08	0.39604E 06	0.38815E 07	-0.11028E 07
5	0.14409E 08	0.29260E 06	0.47966E 06	-0.87896E 07

FIRST 5 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.29548E 07	0.10446E 07	0.11088E 03	-0.27837E 06
2	0.55379E 07	0.86059E 06	0.10040E 03	-0.47467E 06
3	0.90149E 07	0.48853E 06	0.70616E 07	-0.62367E 06
4	0.12608E 08	0.33375E 06	0.78214E 06	-0.53798E 07
5	0.16211E 08	0.26146E 06	0.36842E 06	-0.11505E 08

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE	EFFICIENCY
0.00000E 00	0.99991E 02
0.60000E 01	0.98891E 02
0.12000E 02	0.95642E 02
0.18000E 02	0.90387E 02
0.24000E 02	0.83338E 02
0.30000E 02	0.74802E 02
0.36000E 02	0.65179E 02
0.42000E 02	0.54848E 02
0.48000E 02	0.44205E 02
0.54000E 02	0.33767E 02
0.60000E 02	0.24053E 02
0.66000E 02	0.15495E 02
0.72000E 02	0.84712E 01
0.78000E 02	0.33838E 01
0.84000E 02	0.60305E 00

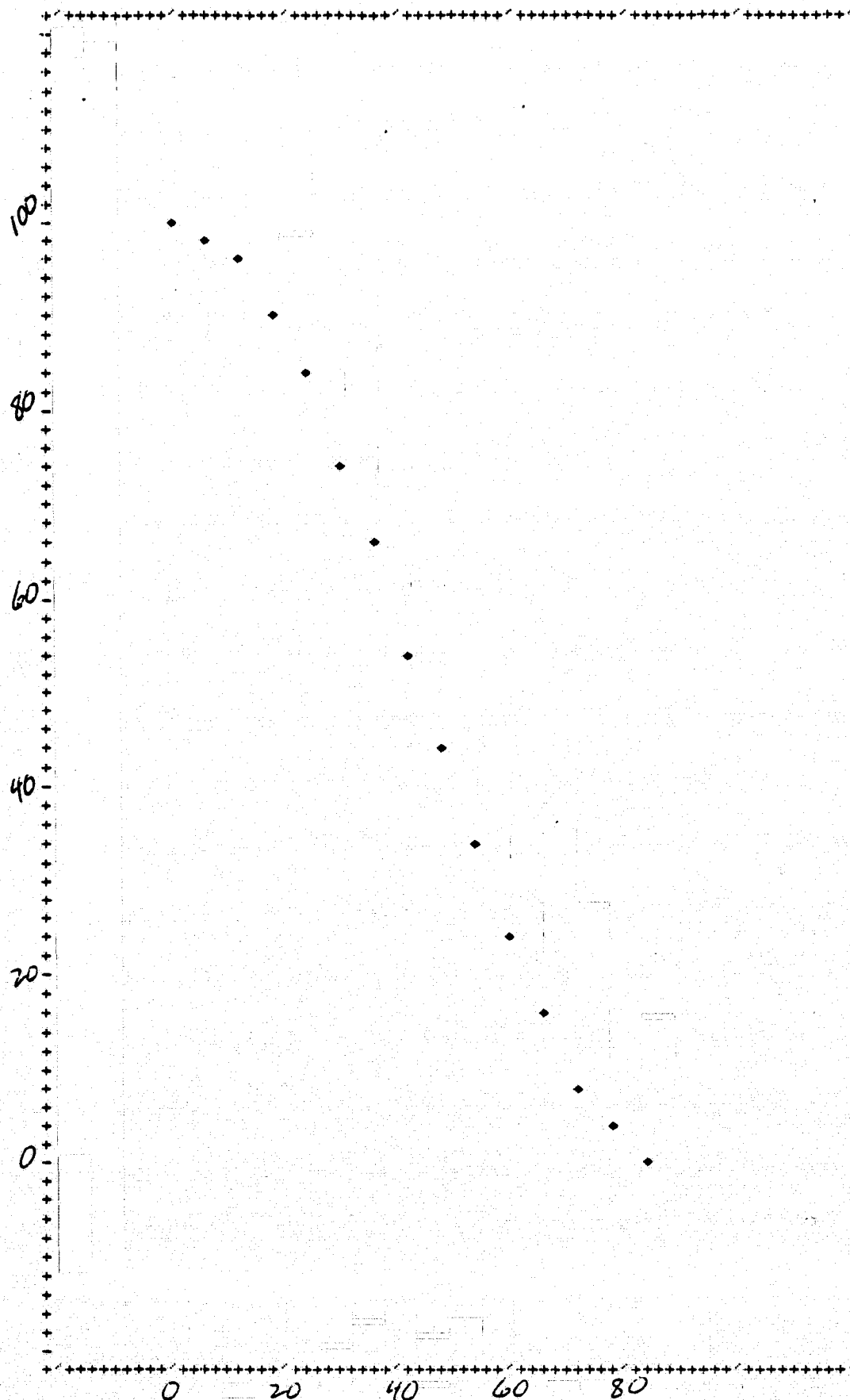


FIG. 8.17 EFFICIENCY VS. ANGLE OF INCIDENCE

TM WAVE, WAVELENGTH=	0.550 MICRONS	HALF-ANGLE OF TAPER=	5.000 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.100
DIELECTRIC CONSTANT=	10.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000		
CONDUCTIVITY=	0.000 MHQS/METER		

TABLE B.18

TE WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 5.000 DEGREES
 DIELECTRIC CONSTANT= 1.000 LOSS TANGENT= 0.000
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 3000.000 MHOS/METER

IMPEDANCE OF MEDIUM= 0.37536E 03 + J 0.18522E 02 OHMS

FIRST 7 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.17748E 07	0.17883E 06	0.11287E 08	-0.28121E 05
2	0.53055E 07	0.56678E 06	0.10137E 08	-0.29662E 06
3	0.86977E 07	0.10508E 07	0.75774E 07	-0.12061E 07
4	0.11645E 08	0.14133E 07	0.38705E 07	-0.42521E 07
5	0.14681E 08	0.11270E 07	0.17749E 07	-0.93224E 07
6	0.18131E 08	0.83932E 06	0.10796E 07	-0.14096E 08
7	0.21699E 08	0.66854E 06	0.78615E 06	-0.18452E 08

FIRST 7 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.35428E 07	0.37069E 06	0.10868E 08	-0.12084E 06
2	0.70412E 07	0.79182E 06	0.90518E 07	-0.61595E 06
3	0.10215E 08	0.13023E 07	0.57609E 07	-0.23093E 07
4	0.13097E 08	0.13110E 07	0.25386E 07	-0.67640E 07
5	0.16382E 08	0.96544E 06	0.13428E 07	-0.11778E 08
6	0.19917E 08	0.74337E 06	0.90703E 06	-0.16324E 08
7	0.23479E 08	0.60788E 06	0.69570E 06	-0.20515E 08

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE EFFICIENCY

0.00000E 00	0.99751E 02
0.60000E 01	0.98655E 02
0.12000E 02	0.95407E 02
0.18000E 02	0.90150E 02
0.24000E 02	0.83112E 02
0.30000E 02	0.74582E 02
0.36000E 02	0.64929E 02
0.42000E 02	0.54567E 02
0.48000E 02	0.43907E 02
0.54000E 02	0.33387E 02
0.60000E 02	0.23503E 02
0.66000E 02	0.14791E 02
0.72000E 02	0.77796E 01
0.78000E 02	0.29290E 01
0.84000E 02	0.47665E 00

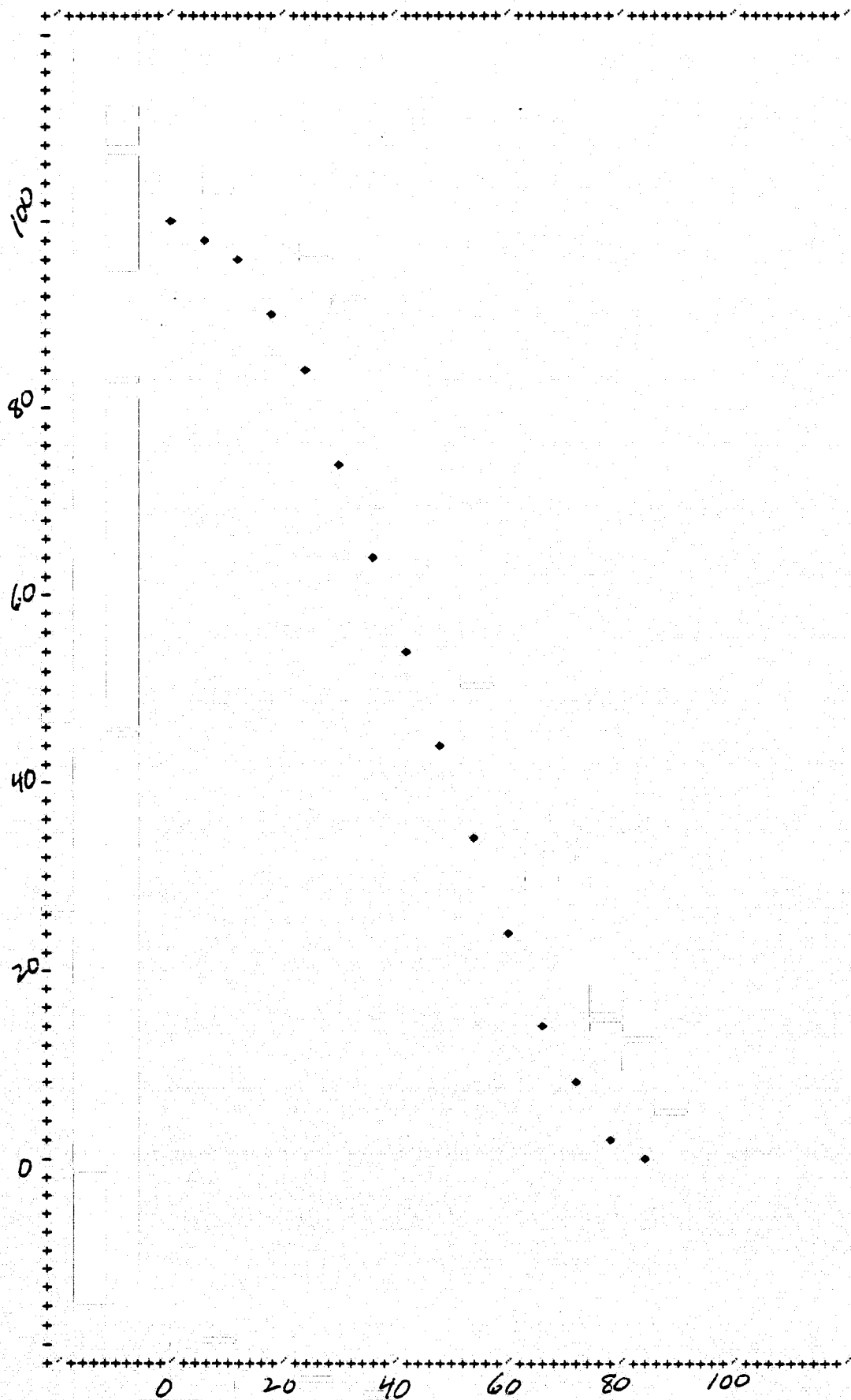


FIG. 8.18 EFFICIENCY VS. ANGLE OF INCIDENCE

TE WAVE, WAVELENGTH=	0.550 MICRONS	HALF-ANGLE OF TAPER=	5.000 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.000
DIELECTRIC CONSTANT=	1.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000		
CONDUCTIVITY=	3000.000 MHOS/METER		

TABLE B.19

TM WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 5.000 DEGREES
 DIELECTRIC CONSTANT= 1.000 LOSS TANGENT= 0.000
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 3000.000 MHOS/METER

IMPEDANCE OF MEDIUM= 0.37536E 03 + J 0.18522E 02 OHMS

FIRST 7 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.17926E 07	0.18349E 06	0.11284E 08	-0.29150E 05
2	0.53637E 07	0.58843E 06	0.10109E 08	-0.31223E 06
3	0.88268E 07	0.11733E 07	0.74760E 07	-0.13853E 07
4	0.11559E 08	0.17067E 07	0.44303E 07	-0.44530E 07
5	0.14484E 08	0.12066E 07	0.19350E 07	-0.90316E 07
6	0.18022E 08	0.85386E 06	0.11026E 07	-0.13956E 08
7	0.21610E 08	0.66828E 06	0.78707E 06	-0.18349E 08

FIRST 7 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.35826E 07	0.38232E 06	0.10855E 08	-0.12618E 06
2	0.71199E 07	0.84282E 06	0.89983E 07	-0.66689E 06
3	0.10311E 08	0.15554E 07	0.58428E 07	-0.27450E 07
4	0.16239E 08	0.99615E 06	0.13967E 07	-0.11582E 08
5	0.19815E 08	0.74969E 06	0.91704E 06	-0.16199E 08
6	0.23410E 08	0.61109E 06	0.70001E 06	-0.20437E 08
7	0.27015E 08	0.51594E 06	0.56933E 06	-0.24481E 08

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE EFFICIENCY

0.00000E 00	0.99760E 02
0.60000E 01	0.98670E 02
0.12000E 02	0.95410E 02
0.18000E 02	0.90169E 02
0.24000E 02	0.83149E 02
0.30000E 02	0.74569E 02
0.36000E 02	0.64945E 02
0.42000E 02	0.54650E 02
0.48000E 02	0.43897E 02
0.54000E 02	0.33230E 02
0.60000E 02	0.23346E 02
0.66000E 02	0.14746E 02
0.72000E 02	0.78189E 01
0.78000E 02	0.29693E 01
0.84000E 02	0.48566E 00

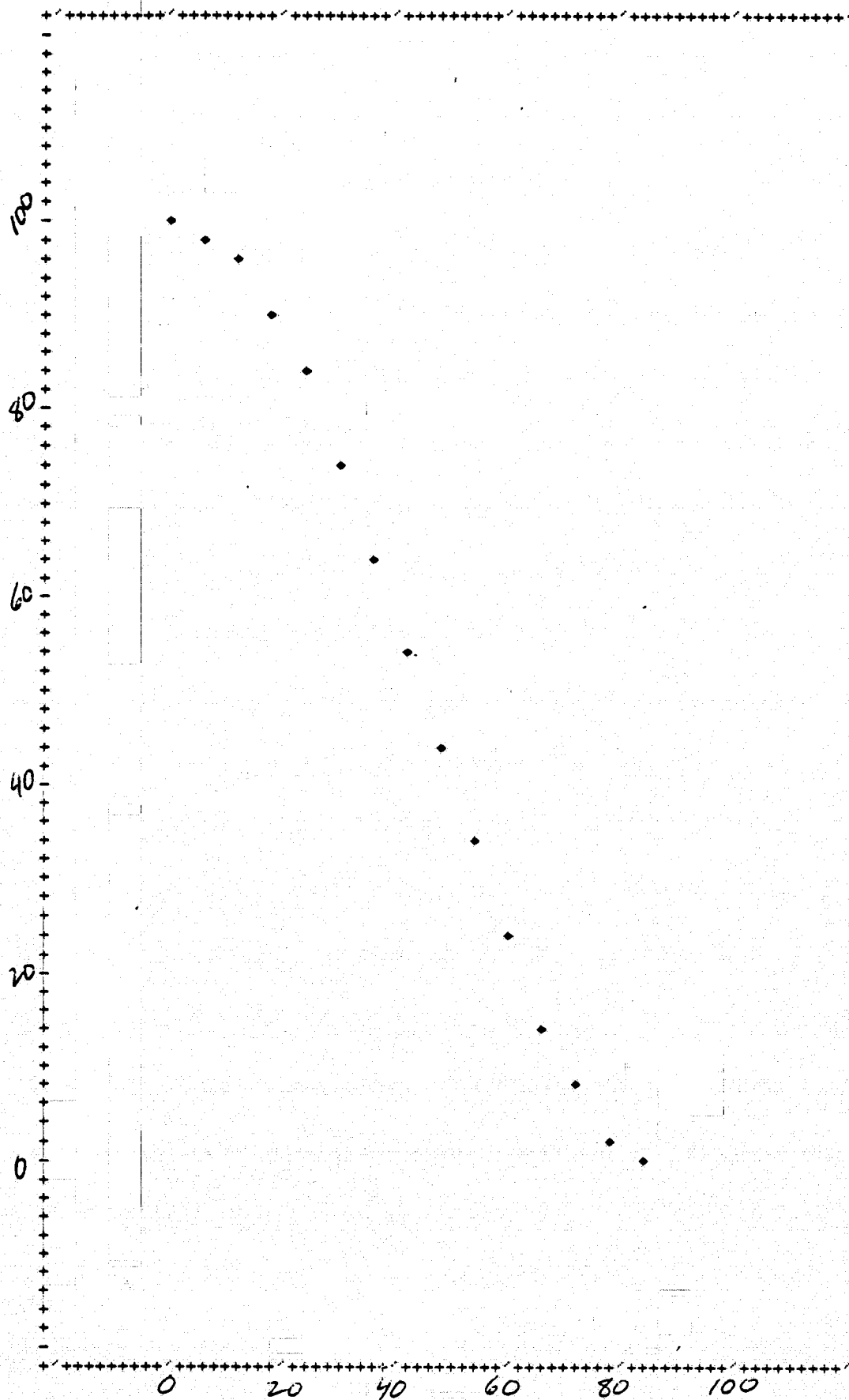


FIG. 8.19 EFFICIENCY VS. ANGLE OF INCIDENCE

TM WAVE, WAVELENGTH=	0.550 MICRONS	HALF-ANGLE OF TAPER=	5.000 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.000
DIELECTRIC CONSTANT=	1.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000	LOSS TANGENT=	0.000
CONDUCTIVITY=	3000.000 MHQS/METER		

TABLE B.20

TE WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 5.000 DEGREES
 DIELECTRIC CONSTANT= 1.000 LOSS TANGENT= 0.000
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 30000.000 MHOS/METER

IMPEDANCE OF MEDIUM= 0.29379E 03 + J 0.12077E 03 OHMS

FIRST 7 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.17349E 07	0.13193E 06	0.11292E 08	-0.20268E 05
2	0.51888E 07	0.39531E 06	0.10187E 08	-0.20135E 06
3	0.85637E 07	0.64452E 06	0.76230E 07	-0.72406E 06
4	0.11889E 08	0.81415E 06	0.24184E 07	-0.40024E 07
5	0.15164E 08	0.83384E 06	0.12623E 07	-0.10017E 08
6	0.18546E 08	0.75445E 06	0.95694E 06	-0.14622E 08
7	0.22021E 08	0.65533E 06	0.76639E 06	-0.18830E 08

FIRST 7 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.34621E 07	0.26465E 06	0.10890E 08	-0.84134E 05
2	0.68993E 07	0.52561E 06	0.91292E 07	-0.39723E 06
3	0.10234E 08	0.74541E 06	0.53273E 07	-0.14319E 07
4	0.13517E 08	0.83327E 06	0.15347E 07	-0.73387E 07
5	0.16845E 08	0.80073E 06	0.10877E 07	-0.12401E 08
6	0.20275E 08	0.70438E 06	0.85225E 06	-0.16757E 08
7	0.23772E 08	0.61020E 06	0.69573E 06	-0.20850E 08

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE	EFFICIENCY
0.00000E 00	0.99700E 02
0.60000E 01	0.98605E 02
0.12000E 02	0.95361E 02
0.18000E 02	0.90107E 02
0.24000E 02	0.83080E 02
0.30000E 02	0.74569E 02
0.36000E 02	0.64939E 02
0.42000E 02	0.54624E 02
0.48000E 02	0.44047E 02
0.54000E 02	0.33614E 02
0.60000E 02	0.23781E 02
0.66000E 02	0.15074E 02
0.72000E 02	0.80221E 01
0.78000E 02	0.30790E 01
0.84000E 02	0.51620E 00

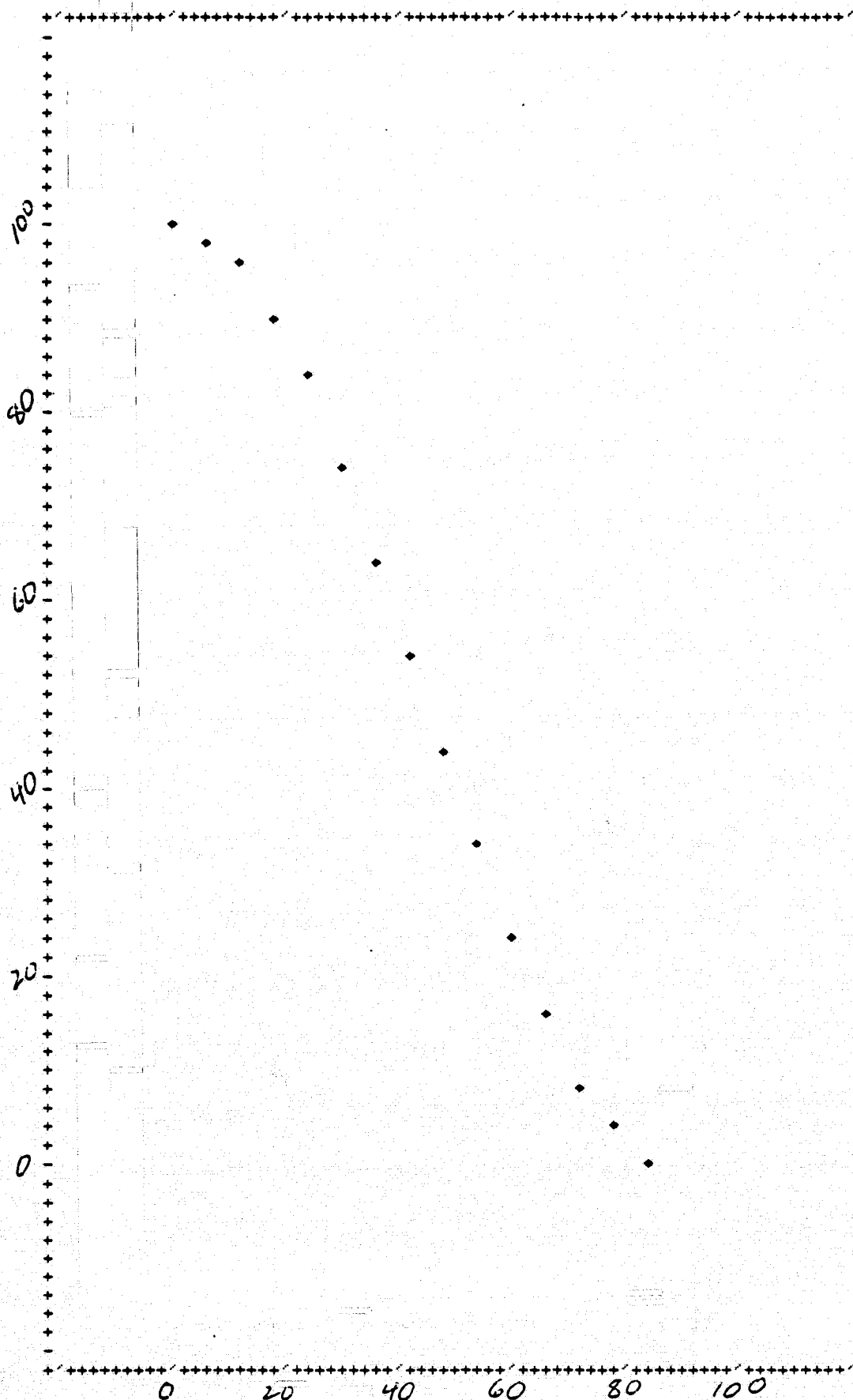


FIG. 8.20 EFFICIENCY VS. ANGLE OF INCIDENCE

TE WAVE, WAVELENGTH=	0.550 MICRONS	HALF-ANGLE OF TAPER=	5.000 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.000
DIELECTRIC CONSTANT=	1.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000	CONDUCTIVITY=	30000.000 MHOS/METER

TABLE B.21

TM WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 5.000 DEGREES
 DIELECTRIC CONSTANT= 1.000 LOSS TANGENT= 0.000
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 30000.000 MHOS/METER

IMPEDANCE OF MEDIUM= 0.29379E 03 + J 0.12077E 03 OHMS

FIRST 7 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.18662E 07	0.21789E 06	0.11273E 08	-0.36073E 05
2	0.56576E 07	0.71193E 06	0.99584E 07	-0.40447E 06
3	0.10005E 08	0.11186E 07	0.59345E 07	-0.18858E 07
4	0.14010E 08	0.79376E 06	0.13587E 07	-0.81852E 07
5	0.17736E 08	0.60822E 06	0.79457E 06	-0.13576E 08
6	0.21409E 08	0.49588E 06	0.58625E 06	-0.18109E 08
7	0.25047E 08	0.41952E 06	0.47139E 06	-0.22291E 08

FIRST 7 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.37334E 07	0.44772E 06	0.10807E 08	-0.15467E 06
2	0.77008E 07	0.10237E 07	0.85500E 07	-0.92201E 06
3	0.12073E 08	0.93741E 06	0.24937E 07	-0.45385E 07
4	0.15893E 08	0.68839E 06	0.98816E 06	-0.11072E 08
5	0.19577E 08	0.54614E 06	0.67231E 06	-0.15903E 08
6	0.23232E 08	0.45430E 06	0.52170E 06	-0.20230E 08
7	0.26867E 08	0.38964E 06	0.43049E 06	-0.24317E 08

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE	EFFICIENCY
0.00000E 00	0.99852E 02
0.60000E 01	0.98751E 02
0.12000E 02	0.95507E 02
0.18000E 02	0.90254E 02
0.24000E 02	0.83202E 02
0.30000E 02	0.74661E 02
0.36000E 02	0.64988E 02
0.42000E 02	0.54577E 02
0.48000E 02	0.43882E 02
0.54000E 02	0.33365E 02
0.60000E 02	0.23502E 02
0.66000E 02	0.14807E 02
0.72000E 02	0.78086E 01
0.78000E 02	0.29550E 01
0.84000E 02	0.48477E 00

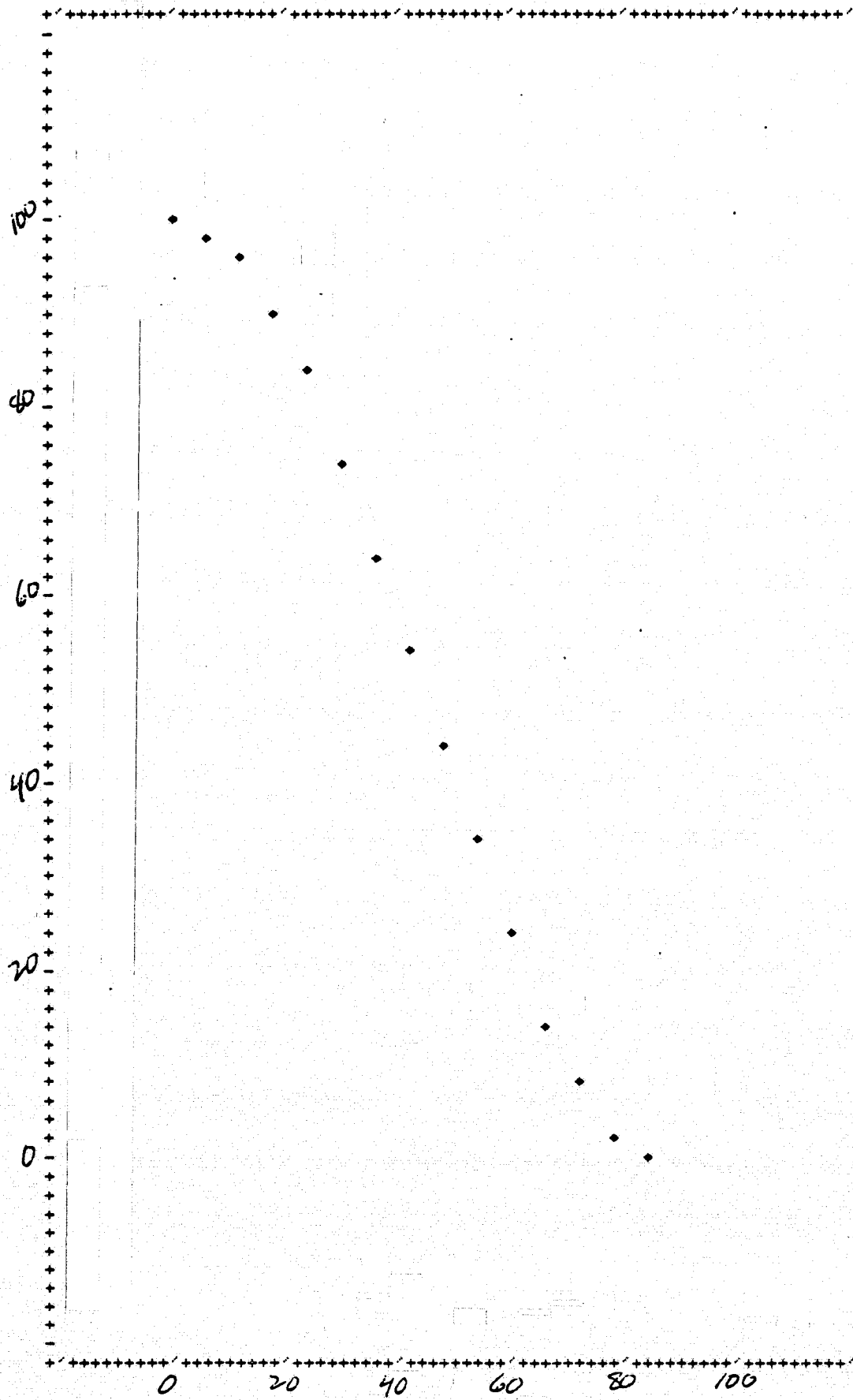


FIG. 8.21 EFFICIENCY VS. ANGLE OF INCIDENCE

TM WAVE, WAVELENGTH=	0.350 MICRONS	HALF-ANGLE OF TAPER=	5.000 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.000
DIELECTRIC CONSTANT=	1.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000	LOSS TANGENT=	0.000
CONDUCTIVITY=	30000.000 MHOS/METER		

TABLE B.22

TE WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 5.000 DEGREES
 DIELECTRIC CONSTANT= 1.000 LOSS TANGENT= 0.000
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 300000.000 MHOS/METER

IMPEDANCE OF MEDIUM= 0.38624E 02 + J 0.80118E 02 OHMS

FIRST 7 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.17637E 07	0.40798E 05	0.11287E 08	-0.63749E 04
2	0.52896E 07	0.12119E 06	0.10127E 08	-0.63302E 05
3	0.88122E 07	0.19816E 06	0.72767E 07	-0.23998E 06
4	0.12330E 08	0.26875E 06	0.70732E 06	-0.46847E 07
5	0.15843E 08	0.34599E 06	0.49912E 06	-0.10982E 08
6	0.19368E 08	0.40391E 06	0.50010E 06	-0.15642E 08
7	0.22863E 08	0.45185E 06	0.52159E 06	-0.19806E 08

FIRST 7 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.35269E 07	0.81243E 05	0.10866E 08	-0.26369E 05
2	0.70514E 07	0.16028E 06	0.89903E 07	-0.12571E 06
3	0.10572E 08	0.23446E 06	0.43730E 07	-0.56681E 06
4	0.14087E 08	0.31560E 06	0.53866E 06	-0.82536E 07
5	0.17598E 08	0.37584E 06	0.49396E 06	-0.13389E 08
6	0.21124E 08	0.43038E 06	0.51160E 06	-0.17770E 08
7	0.24619E 08	0.47600E 06	0.53732E 06	-0.21810E 08

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE EFFICIENCY

0.00000E 00	0.99681E 02
0.60000E 01	0.98534E 02
0.12000E 02	0.95296E 02
0.18000E 02	0.90104E 02
0.24000E 02	0.83032E 02
0.30000E 02	0.74527E 02
0.36000E 02	0.64999E 02
0.42000E 02	0.54698E 02
0.48000E 02	0.44083E 02
0.54000E 02	0.33741E 02
0.60000E 02	0.24122E 02
0.66000E 02	0.15583E 02
0.72000E 02	0.85211E 01
0.78000E 02	0.33975E 01
0.84000E 02	0.60442E 00

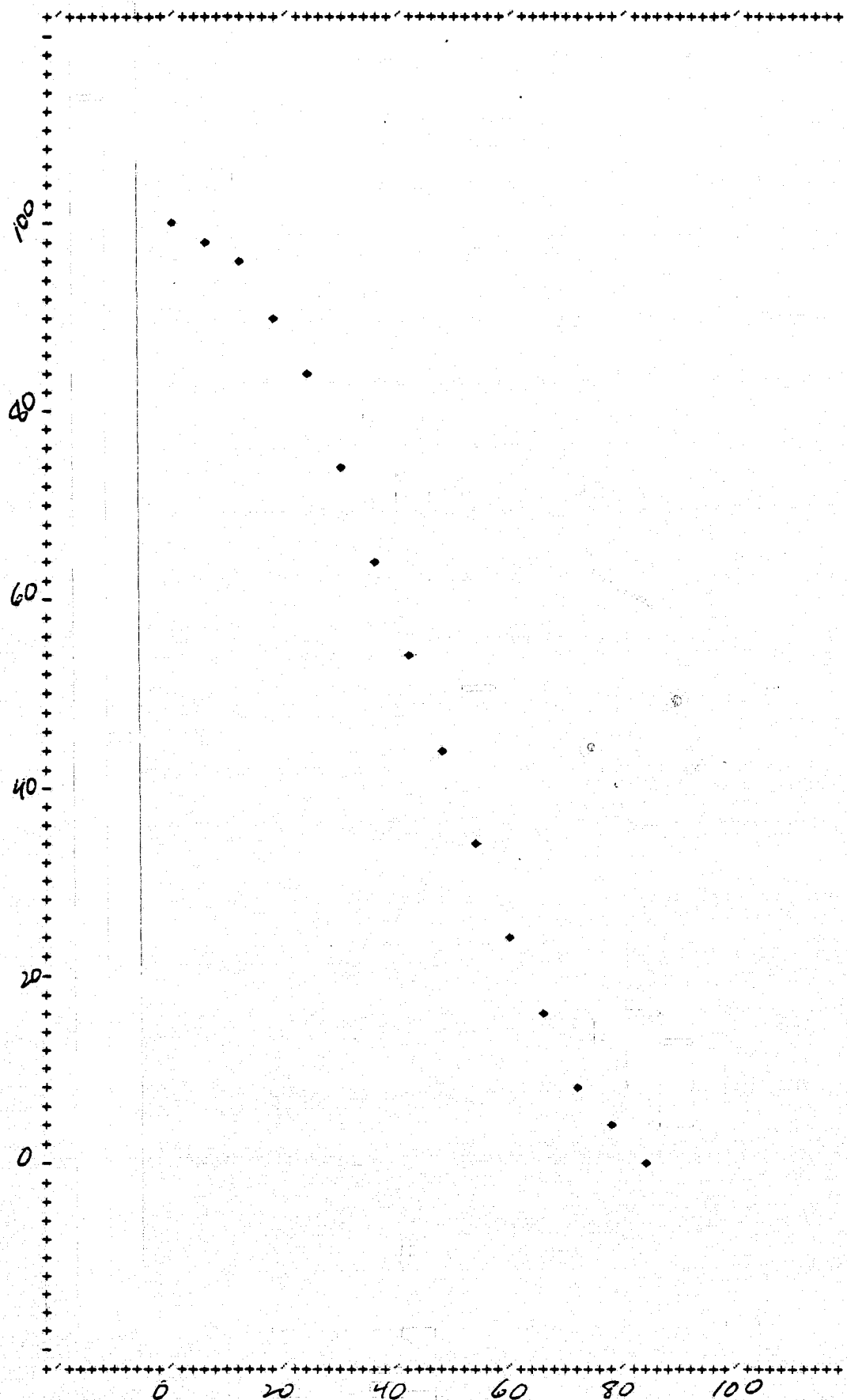


FIG. 8.22 EFFICIENCY VS. ANGLE OF INCIDENCE

TE WAVE, WAVELENGTH=	0.550 MICRONS	HALF-ANGLE OF TAPER=	5.000 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.000
DIELECTRIC CONSTANT=	1.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000	LOSS TANGENT=	0.000
CONDUCTIVITY=	300000.000 MHQS/METER		

TABLE B.23

TM WAVE, WAVELENGTH= 0.550 MICRONS
 LENGTH OF TAPER= 10.000 MICRONS HALF-ANGLE OF TAPER= 5.000 DEGREES
 DIELECTRIC CONSTANT= 1.000 LOSS TANGENT= 0.000
 RELATIVE PERMEABILITY= 1.000 LOSS TANGENT= 0.000
 CONDUCTIVITY= 300000.000 MHOS/METER

IMPEDANCE OF MEDIUM= 0.88624E 02 + J 0.80118E 02 OHMS

FIRST 7 WAVE NUMBERS FOR EVEN MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.22532E 07	0.66071E 06	0.11220E 08	-0.13268E 06
2	0.67826E 07	0.44516E 06	0.92092E 07	-0.32786E 06
3	0.10547E 08	0.29043E 06	0.44522E 07	-0.68804E 06
4	0.14218E 08	0.21664E 06	0.36369E 06	-0.84693E 07
5	0.17865E 08	0.17119E 06	0.22265E 06	-0.13735E 08
6	0.21497E 08	0.14265E 06	0.16839E 06	-0.18210E 08
7	0.25120E 08	0.12226E 06	0.13727E 06	-0.22372E 08

FIRST 7 WAVE NUMBERS FOR ODD MODES

MODE	REAL(KX)	IMAG(KX)	REAL(KY)	IMAG(KY)
1	0.26364E 07	0.25075E 07	0.11410E 08	-0.57941E 06
2	0.47704E 07	0.61295E 06	0.10402E 08	-0.28110E 06
3	0.86856E 07	0.35104E 06	0.74404E 07	-0.40979E 06
4	0.12389E 08	0.24763E 06	0.63516E 06	-0.48302E 07
5	0.16044E 08	0.19021E 06	0.27086E 06	-0.11267E 08
6	0.19682E 08	0.15562E 06	0.19110E 06	-0.16028E 08
7	0.23309E 08	0.13167E 06	0.15105E 06	-0.20318E 08

TABULATION OF EFFICIENCY

ANGLE OF INCIDENCE	EFFICIENCY
0.00000E 00	0.99938E 02
0.60000E 01	0.98840E 02
0.12000E 02	0.95595E 02
0.18000E 02	0.90320E 02
0.24000E 02	0.83245E 02
0.30000E 02	0.74766E 02
0.36000E 02	0.65152E 02
0.42000E 02	0.54794E 02
0.48000E 02	0.44217E 02
0.54000E 02	0.33883E 02
0.60000E 02	0.24191E 02
0.66000E 02	0.15568E 02
0.72000E 02	0.84744E 01
0.78000E 02	0.33610E 01
0.84000E 02	0.59227E 00

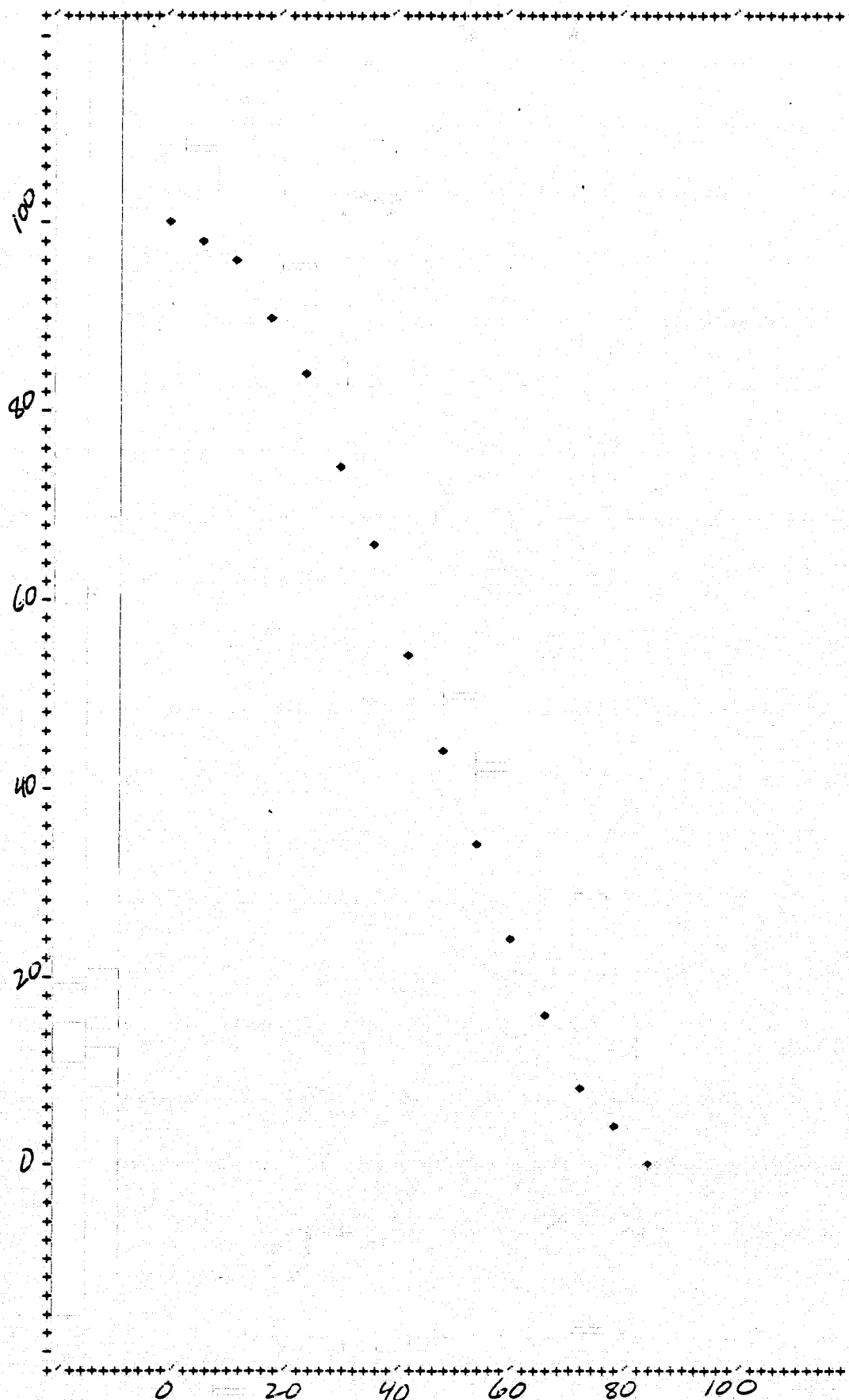


FIG. 8.23 EFFICIENCY VS. ANGLE OF INCIDENCE

TM WAVE, WAVELENGTH=	0.550 MICRONS	HALF-ANGLE OF TAPER=	5.000 DEGREES
LENGTH OF TAPER=	10.000 MICRONS	LOSS TANGENT=	0.000
DIELECTRIC CONSTANT=	1.000	LOSS TANGENT=	0.000
RELATIVE PERMEABILITY=	1.000		
CONDUCTIVITY=	300000.000 MHQS/METER		

Appendix C. FORTRAN Program to Evaluate Efficiency.

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100 REAL L,MUREL,K0
110 COMMON /GEO/ L,WAVEL,ALPHA,THETA,THSTOP,THINC
120 COMMON /MAT/ EPSREL,MUREL,TAN,TANMAG,SIG
130 COMMON /WAVEN/ K0,NTERMS,KXC(20),KYC(20),KXS(20),KYS(20)
140 COMMON /KEYS/ ITAB,IWAV
150 COMMON /PERB/ ITYPE
160 COMPLEX KXC,KYC,KXS,KYS
170 DATA PI,C/ 3.141592654,2.99792456E8/
180 WRITE (9,100)
190 100 FORMAT (1X,'GEOMETRIC PARAMETERS',/,5X,
200 +'/LENGTH OF WEDGE IN MICRONS ')
210 READ (9,110) L
220 110 FORMAT (3F13.0)
230 L=L*1.E-6
240 WRITE (9,120)
250 120 FORMAT (5X,'HALF-ANGLE OF WEDGE IN DEGREES ')
260 READ (9,110) ALPHA
270 ALPHA=ALPHA*PI/180
280 WRITE (9,130)
290 130 FORMAT (5X,'ANGLES OF INCIDENCE IN DEGREES (START, STOP, STEP) ')
300 READ (9,110) THETA,THSTOP,THINC
310 THETA=THETA*PI/180
320 IF (ABS(THSTOP-90).LE.0.1) THSTOP=89.9
330 THSTOP=THSTOP*PI/180
340 THINC=THINC*PI/180
350 WRITE (9,140)
360 140 FORMAT (5X,'WAVELENGTH IN MICRONS ')
370 READ (9,110) WAVEL
380 WAVEL=WAVEL*1.E-6
390 WRITE (9,150)
400 150 FORMAT (1X,/,1X,'MATERIAL CONSTANTS',/,
410 +5X,'DIELECTRIC CONSTANT ')
420 READ (9,110) EPSREL
430 WRITE (9,160)
440 160 FORMAT (5X,'LOSS TANGENT ')
450 READ (9,110) TAN
460 WRITE (9,170)
470 170 FORMAT (5X,'RELATIVE PERMEABILITY ')
480 READ (9,110) MUREL
490 WRITE (9,180)
500 180 FORMAT (5X,'MAGNETIC LOSS TANGENT ')
510 READ (9,110) TANMAG
520 WRITE (9,190)
530 190 FORMAT (5X,'CONDUCTIVITY IN MHOS/METER ')
540 READ (9,110) SIG
550 WRITE (9,200)
560 200 FORMAT (1X,/,1X,'TE OR TM TYPE WAVE? (1 OR 2?) ')
570 READ (9,210) IWAV
580 210 FORMAT (I10)
590 APER=2*L*SIN(ALPHA)/WAVEL
600 WRITE (9,220) APER
610 220 FORMAT (1X,/,1X,'APERTURE IS ',F8.3,' WAVELENGTHS ACROSS',
620 +/,1X,'NUMBER OF MODES ')
630 READ (9,210) NTERMS
640 WAV=WAVEL/1.E-6
650 TAPER=L/1.E-6

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660 ALPH=ALPHA*180/PI
670 IF (IWAY.EQ.1) WRITE (9,300) WAV
680 IF (IWAY.EQ.2) WRITE (9,400) WAV
690 WRITE (9,500) TAPER,ALPH,EPSREL,TAN,MUREL,TANMAG,SIG
700 300 FORMAT (1X,/,25X,'TABLE',/,1X,'TE WAVE, WAVELENGTH= ',
710 +F8.3,' MICRONS')
720 400 FORMAT (1X,/,25X,'TABLE',/,1X,'TM WAVE, WAVELENGTH= ',
730 +F8.3,' MICRONS')
740 500 FORMAT (1X,'LENGTH OF TAPER= ',F8.3,' MICRONS',5X,
750 +'HALF-ANGLE OF TAPER= ',F8.3,' DEGREES',/,1X,'DIELECTRIC CONSTANT= ',
760 +F8.3,9X,'LOSS TANGENT= ',F8.3,/,1X,'RELATIVE ',
770 +'PERMEABILITY= ',F8.3,7X,'LOSS TANGENT= ',F8.3,/,1X,
780 +'CONDUCTIVITY= ',F8.3,' MHOS/METER')
790 CALL WAVNUM(IWAY)
800 CALL CHAIN ('SEG2,')
810 STOP
820 END
830 ◆
840 ◆ CALCULATE WAVE NUMBERS FOR BOUND MODES
850 ◆
860 SUBROUTINE WAVNUM(IWAY)
870 COMMON /GEO/ L,WAVEL,ALPHA,THETA
880 COMMON /MAT/ EPSREL,MUREL,TAN,TANMAG,SIG
890 COMMON /WAVEN/ K0,NTERMS,KXC(20),KYC(20),KXS(20),KYS(20)
900 REAL K0,L,MUREL,MU0
910 COMPLEX J,ETA,WEVEN,WODD,CSQRT,KXC,KYC,KXS,KYS,Z
920 DATA PI,C,ETA0 /3.141592654,2.99792456E8,376.7304/
930 DATA EPS0,MU0 /8.854185E-12,12.566371E-7/
940 J=CMPLX(0.,1.)
950 K0=2*PI/WAVEL
960 OMEGA=C*K0
970 ETA=CSQRT((MU0*MUREL*(1-J*TANMAG))/(EPS0*EPSREL*(1-J*TAN)-J*SIG/
980 +OMEGA))
990 T1=L*SIN(ALPHA)
1000 T2=K0*T1
1010 IF (IWAY.EQ.1) WEVEN=J*ETA0/ETA+T2
1020 IF (IWAY.EQ.2) WEVEN=J*ETA/ETA0+T2
1030 IF (IWAY.EQ.1) WODD=-J*ETA0/ETA+T2
1040 IF (IWAY.EQ.2) WODD=-J*ETA/ETA0+T2
1050 ICOUNT=1
1060 N=0
1070 100 CONTINUE
1080 N=N+1
1090 CALL ZTANZ(N,WEVEN,Z,ERRR)
1100 IF (REAL(Z).LT.0.) GO TO 100
1110 KXC(ICOUNT)=Z/T1
1120 IF (ICOUNT.GT.1.AND.CABS(KXC(ICOUNT)-KXC(ICOUNT-1)).LE.
1130 +.01*CABS(KXC(ICOUNT))) GO TO 100
1140 KYC(ICOUNT)=CSQRT(K0**2-KXC(ICOUNT)**2)
1150 IF (REAL(KYC(ICOUNT)).LT.0.) KYC(ICOUNT)=-KYC(ICOUNT)
1160 ICOUNT=ICOUNT+1
1170 IF (ICOUNT.LE.NTERMS) GO TO 100
1180 ICOUNT=1
1190 N=0
1200 200 CONTINUE
1210 N=N+1

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```

1220 CALL ZCOTZ(N,WDD,Z,ERRR)
1230 IF (REAL(Z).LT.0.) GO TO 200
1240 KXS(ICOUNT)=Z/T1
1250 IF (ICOUNT.GT.1.AND.CABS(KXS(ICOUNT)-KXS(ICOUNT-1)).LE.
1260 +.01+CABS(KXS(ICOUNT))) GO TO 200
1270 KYS(ICOUNT)=CSQRT(K0**2-KXS(ICOUNT)**2)
1280 IF (REAL(KYS(ICOUNT)).LT.0.) KYS(ICOUNT)=-KYS(ICOUNT)
1290 ICOUNT=ICOUNT+1
1300 IF (ICOUNT.LE.NTERMS) GO TO 200
1310 WRITE (9,300) ETA
1320 300 FORMAT (1X,/,1X,'IMPEDANCE OF MEDIUM= ',E12.5,' + J ',E12.5,
1330 +' OHMS',/)
1340 WRITE (9,400) NTERMS
1350 400 FORMAT (1X,'FIRST ',I4,' WAVE NUMBERS FOR EVEN MODES',/)
1360 WRITE (9,450)
1370 450 FORMAT (2X,'MODE',4X,'REAL(KX)',5X,'IMAG(KX)',7X,'REAL(KY)',
1380 +5X,'IMAG(KY)',/)
1390 DO 600 M=1,NTERMS
1400 WRITE (9,500) M,KXC(M),KYC(M)
1410 500 FORMAT (1X,I4,4(2X,E12.5))
1420 600 CONTINUE
1430 WRITE (9,700) NTERMS
1440 700 FORMAT (1X,/,1X,'FIRST ',I4,' WAVE NUMBERS FOR ODD MODES',/)
1450 WRITE (9,450)
1460 DO 800 M=1,NTERMS
1470 WRITE (9,500) M,KXS(M),KYS(M)
1480 800 CONTINUE
1490 RETURN
1500 END
1510 *
1520 * THIS SUBROUTINE FINDS APPROXIMATELY THE MTH ROOT OF THE
1530 * EQUATION Z+TAN(Z)=W
1540 *
1550 SUBROUTINE ZTANZ(M,W,Z,ERRR)
1560 COMPLEX Z,W,CSQRT,Z1,Z2,Z3,Z4,C1,C2,C3,C4,C33,C44
1570 REAL NUUDJ,MNUUDJ
1580 COMMON /PERB/ ITYPE
1590 DATA PI /3.141592654/
1600 ITYPE=1
1610 M=M-1
1620 *
1630 * CHECK FOR EASY SOLUTIONS FIRST
1640 *
1650 IF (CABS(W).LT..1+M*PI) GO TO 20
1660 IF (CABS(W).GT.10+(2*M-1)*PI/2) GO TO 30
1670 *
1680 * EXPANSIONS ABOUT LIKELY POINTS
1690 *
1700 T1=N*PI
1710 C1=1+W/2
1720 Z1=T1+(-T1+CSQRT(T1**2+4*W*C1))/2/C1
1730 T2=(2*N+1)*PI/2
1740 C2=W+1
1750 Z2=T2+(C2-CSQRT(C2**2+2*T2**2))/T2
1760 T3=(4*M+1)*PI/4
1770 C3=1+W

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1780 C33=1+(W-T3)/2
1790 Z3=T3+((-C3+T3)+CSQRT((C3+T3)♦♦2+4♦C33♦(W+T3)))/(2♦C33)
1800 T4=(4♦M+3)♦PI/4
1810 C4=1+W
1820 C44=1+(W+T4)/2
1830 Z4=T4+((C4-T4)-CSQRT((C4-T4)♦♦2+4♦C44♦(W+T4)))/(2♦C44)
1840 ERR1=ERRTAN(Z1,W)
1850 ERR2=ERRTAN(Z2,W)
1860 ERR3=ERRTAN(Z3,W)
1870 ERR4=ERRTAN(Z4,W)
1880 ERRR=AMIN1(ERR1,ERR2,ERR3,ERR4)
1890 IF (ERRR.EQ.ERR1) Z=Z1
1900 IF (ERRR.EQ.ERR2) Z=Z2
1910 IF (ERRR.EQ.ERR3) Z=Z3
1920 IF (ERRR.EQ.ERR4) Z=Z4
1930 ♦
1940 ♦ IMPROVE SOLUTION BY PERTURBATION
1950 ♦
1960 NUDJ=.1
1970 NNUDJ=-.1
1980 ICOUNT=1
1990 10 CONTINUE
2000 IF (ERRR.LE..01♦CABS(W).OR.ICOUNT.GE.14) RETURN
2010 CALL REFINE (Z,W,ERRR,NUDJ,0.)
2020 CALL REFINE (Z,W,ERRR,NNUDJ,0.)
2030 CALL REFINE (Z,W,ERRR,0.,NUDJ)
2040 CALL REFINE (Z,W,ERRR,0.,NNUDJ)
2050 NUDJ=NUDJ/2
2060 NNUDJ=NNUDJ/2
2070 ICOUNT=ICOUNT+1
2080 GO TO 10
2090 20 CONTINUE
2100 Z=((N♦PI)♦♦2+W)/(N♦PI)
2110 ERRR=ERRTAN(Z,W)
2120 RETURN
2130 30 CONTINUE
2140 Z=(2♦M-1)♦PI/2+W/(1+W)
2150 ERRR=ERRTAN(Z,W)
2160 RETURN
2170 END
2180 ♦
2190 ♦ THIS SUBROUTINE FINDS APPROXIMATELY THE NTH ROOT OF THE
2200 ♦ EQUATION Z♦COT(Z)=W
2210 ♦
2220 SUBROUTINE ZCOTZ(N,W,Z,ERRR)
2230 COMPLEX Z,W,CSQRT,Z1,Z2,C1,C2
2240 REAL NUDJ,NNUDJ
2250 COMMON /PERB/ ITYPE
2260 DATA PI /3.141592654/
2270 ITYPE=2
2280 5 CONTINUE
2290 ♦
2300 ♦ CHECK FOR EASY SOLUTIONS FIRST
2310 ♦
2320 IF (CABS(W).LT..1♦(2♦M-1)♦PI/2) GO TO 20
2330 IF (CABS(W).GT.10♦N♦PI) GO TO 30

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2340 ◆
2350 ◆ EXPANSIONS ABOUT LIKELY POINTS
2360 ◆
2370 T1=N*PI
2380 C1=1-W
2390 Z1=T1+(C1-CSQRT(C1**2+2*T1**2))/T1
2400 T2=(2*N-1)*PI/2
2410 C2=2-W
2420 Z2=T2-W/T2
2430 IF (W.NE.2.) Z2=T2+(-T2+CSQRT(T2**2-2*W*C2))/C2
2440 ERR1=ERRCOT(Z1,W)
2450 ERR2=ERRCOT(Z2,W)
2460 ERRR=AMIN1(ERR1,ERR2)
2470 IF (ERRR.EQ.ERR1) Z=Z1
2480 IF (ERRR.EQ.ERR2) Z=Z2
2490 ◆
2500 ◆ IMPROVE SOLUTION BY PERTURBATION
2510 ◆
2520 NUDJ=.1
2530 NNUDJ=-.1
2540 ICOUNT=1
2550 10 CONTINUE
2560 IF (ERRR.LE..01+CABS(W)) RETURN
2570 CALL REFINE (Z,W,ERRR,NUDJ,0.)
2580 CALL REFINE (Z,W,ERRR,NNUDJ,0.)
2590 CALL REFINE (Z,W,ERRR,0.,NUDJ)
2600 CALL REFINE (Z,W,ERRR,0.,NNUDJ)
2610 NUDJ=NUDJ/2
2620 NNUDJ=NNUDJ/2
2630 ICOUNT=ICOUNT+1
2640 IF (ICOUNT.LT.14) GO TO 10
2650 ◆
2660 ◆ IF NTH ROOT DOES NOT EXIST (N+1)ST ROOT IS FOUND
2670 ◆
2680 N=N+1
2690 GO TO 5
2700 20 CONTINUE
2710 Z=((((2*N-1)*PI/2)**2-2*W)/((2*N-1)*PI/2)
2720 ERRR=ERRCOT(Z,W)
2730 RETURN
2740 30 CONTINUE
2750 Z=W*N*PI/(W-1)
2760 ERRR=ERRCOT(Z,W)
2770 RETURN
2780 END
2790 SUBROUTINE REFINE(Z,W,ERRR,TX,TY)
2800 COMPLEX Z,W,ZNEW
2810 COMMON /PERB/ ITYPE
2820 10 CONTINUE
2830 X=REAL(Z)
2840 Y=AIMAG(Z)
2850 XNEW=X*(1+TX)
2860 YNEW=Y*(1+TY)
2870 ZNEW=CMPLX(XNEW,YNEW)
2880 IF (ITYPE.EQ.1) ERRNEW=ERRTAN(ZNEW,W)
2890 IF (ITYPE.EQ.2) ERRNEW=ERRCOT(ZNEW,W)

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```

2900 IF (ERRNEW.GE.ERRR) RETURN
2910 ERRR=ERRNEW
2920 Z=ZNEW
2930 GO TO 10
2940 END
2950 ◆
2960 ◆ ERROR CALCULATION FOR  $Z \div \tan(Z) = W$ 
2970 ◆
2980 FUNCTION ERRRTAN(Z,W)
2990 COMPLEX Z,W,CCOS,CSIN,J
3000 DATA PI /3.141592654/
3010 J=CMPLX(0.,1.)
3020 T1=AIMAG(Z)
3030 IF (T1.GE.35.) ERRRTAN=CABS(J+Z-W)
3040 IF (T1.LE.-35.) ERRRTAN=CABS(J+Z+W)
3050 IF (CABS(T1).LT.35.) ERRRTAN=CABS(Z+CSIN(Z)-W+CCOS(Z))
3060 RETURN
3070 END
3080 ◆
3090 ◆ ERROR CALCULATION FOR  $Z \div \cot(Z) = W$ 
3100 ◆
3110 FUNCTION ERRRCOT(Z,W)
3120 COMPLEX Z,W,CCOS,CSIN,J
3130 DATA PI /3.141592654/
3140 J=CMPLX(0.,1.)
3150 T1=AIMAG(Z)
3160 IF (T1.GE.35.) ERRRCOT=CABS(Z-J+W)
3170 IF (T1.LE.-35.) ERRRCOT=CABS(Z+J+W)
3180 IF (CABS(T1).LT.35.) ERRRCOT=CABS(Z+CCOS(Z)-W+CSIN(Z))
3190 IF (CABS(Z).LE..05) ERRRCOT=CABS(1-W)
3200 RETURN
3210 END

```

```

100 REAL L,K0,MUREL
110 COMMON /GEO/ L,WAVEL,ALPHA,THETA,THSTOP,THINC
120 COMMON /MAT/ EPSREL,MUREL,TAN,TANMAG,SIG
130 COMMON /WAVEN/ K0,NTERMS,KXC(20),KYC(20),KXS(20),KYS(20)
140 COMMON /KEYS/ ITAB,IWAV
150 COMMON /PERB/ ITYPE
160 COMPLEX KXC,KYC,KXS,KYS
170 DATA PI,C/ 3.141592654,2.99792456E8/
180 CALL DEFINE(1,'GRAPH,')
190 WRITE (9,100)
200 100 FORMAT (1X,/,1X,'TABULATION OF EFFICIENCY',/,1X,
210 +'ANGLE OF INCIDENCE',5X,'EFFICIENCY',/)
220 300 CONTINUE
230 T1=EFF(IWAV)*100
240 ANGL=THETA*180/PI
250 WRITE (9,200) ANGL,T1
260 WRITE (1,250) ANGL,T1
270 200 FORMAT (2X,E12.5,9X,E12.5)
280 250 FORMAT (2E11.4)
290 THETA=THETA+THINC
300 IF (THETA.LE.THSTOP) GO TO 300
310 CALL GRAF(IWAV)
320 STOP
330 END
340 ◆

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350 ◆ EFFICIENCY

360 ◆

370 FUNCTION EFF(IWAV)

```

380 COMMON /GEO/ L,WAVEL,ALPHA,THETA,THSTOP,THINC
390 COMMON /WAVEN/ K0,NTERMS,KXC(20),KYC(20),KXS(20),KYS(20)
400 REAL L,K0
410 COMPLEX KXC,KYC,KXS,KYS
420 COMPLEX CM,SM,ZMC,ZMS,GAMC,GAMS
430 DATA PI,ETA0 /3.141592654,376.7304/
440 K0=2*PI/WAVEL
450 IF (IWAV.EQ.1) Z0=-ETA0/COS(THETA)
460 IF (IWAV.EQ.2) Z0=-ETA0*COS(THETA)
470 SUM1=0
480 SUM2=0
490 T1=2*L*SIN(ALPHA)
500 DO 100 M=1,NTERMS
510 IF (IWAV.EQ.1) ZMC=-ETA0*K0/KYC(M)
520 IF (IWAV.EQ.2) ZMC=-ETA0*KYC(M)/K0
530 IF (IWAV.EQ.1) ZMS=-ETA0*K0/KYS(M)
540 IF (IWAV.EQ.2) ZMS=-ETA0*KYS(M)/K0
550 IF (REAL(ZMC).GT.0.) ZMC=-ZMC
560 IF (REAL(ZMS).GT.0.) ZMS=-ZMS
570 GAMC=(Z0-ZMC)/(Z0+ZMC)
580 GAMS=(Z0-ZMS)/(Z0+ZMS)
590 IF (IWAV.EQ.1) T2=ABS(REAL(1/ZMC))
600 IF (IWAV.EQ.2) T2=ABS(REAL(ZMC))
610 T3=REAL(KXC(M))*T1
620 TC=CABS(CM(M))*2*T2*(1+SIN(T3)/T3)
630 IF (IWAV.EQ.1) T2=ABS(REAL(1/ZMS))
640 IF (IWAV.EQ.2) T2=ABS(REAL(ZMS))
650 T3=REAL(KXS(M))*T1

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660 TS=CABS(SM(M))◆◆2◆T2◆(1-SIN(T3)/T3)
670 SUM1=SUM1+TC+TS
680 SUM2=SUM2+TC◆CABS(GAMC)◆◆2+TS◆CABS(GAMS)◆◆2
690 100 CONTINUE
700 EFF=COS(THETA)◆◆2◆(SUM1-SUM2)/SUM1
710 RETURN
720 END
730 FUNCTION CM(M)
740 COMMON /GEO/ L,WAVEL,ALPHA,THETA,THSTOP,THINC
750 COMMON /WAVEN/ K0,NTERMS,KXC(20),KYC(20),KXS(20),KYS(20)
760 REAL L,K0
770 COMPLEX I,CM,A,B1,B2
780 COMPLEX KXC,KYC,KXS,KYS
790 DATA PI /3.141592654/
800 A=KYC(M)/(2◆L◆COS(ALPHA))
810 T1=L◆SIN(ALPHA)
820 T2=K0◆SIN(THETA)
830 B1=T2+KXC(M)
840 B2=T2-KXC(M)
850 T3=-T1
860 A=REAL(A)
870 B1=REAL(B1)
880 B2=REAL(B2)
890 CM=(I(A,B2,T1)-I(A,B2,T3)+I(A,B1,T1)-I(A,B1,T3))/(4◆T1)
900 RETURN
910 END
920 FUNCTION SM(M)
930 COMMON /GEO/ L,WAVEL,ALPHA,THETA,THSTOP,THINC
940 COMMON /WAVEN/ K0,NTERMS,KXC(20),KYC(20),KXS(20),KYS(20)
950 REAL L,K0
960 COMPLEX I,SM,A,B1,B2,J
970 COMPLEX KXC,KYC,KXS,KYS
980 DATA PI /3.141592654/
990 J=CMPLX(0.,1.)
1000 A=KYS(M)/(2◆L◆COS(ALPHA))
1010 T1=L◆SIN(ALPHA)
1020 T2=K0◆SIN(THETA)
1030 B1=T2+KXS(M)
1040 B2=T2-KXS(M)
1050 T3=-T1
1060 A=REAL(A)
1070 B1=REAL(B1)
1080 B2=REAL(B2)
1090 SM=(I(A,B2,T1)-I(A,B2,T3)-I(A,B1,T1)+I(A,B1,T3))/(J◆4◆T1)
1100 RETURN
1110 END
1120 ◆
1130 ◆ INTEGRAL OF CEXP(-J◆(A◆X◆◆2+B◆X))
1140 ◆
1150 FUNCTION I(A,B,X)
1160 COMPLEX I,A,B,CSQRT,Z,J,FRESNL
1170 DATA PI /3.141592654/
1180 J=CMPLX(0.,1.)
1190 Z=CSQRT(2/(PI◆A))◆(A◆X+B/2)
1200 I=CSQRT(PI/(2◆A))◆CEXP(J◆B◆◆2/(4◆A))◆FRESNL(Z)
1210 RETURN

```

```

1220 END
1230 ◆
1240 ◆ THIS SUBROUTINE COMPUTES THE FRESNEL INTEGRAL  $F=C-J\cdot S$  FOR
1250 ◆ COMPLEX ARGUMENTS
1260 ◆
1270 FUNCTION FRESNL(ZZ)
1280 COMPLEX ZZ,Z,FRESNL,J,SUM,TERM,CEXP,F0,Z1,W
1290 LOGICAL L1
1300 DATA PI /3.141592654/
1310 L1=REAL(ZZ)◆AIMAG(ZZ).GT.0.
1320 Z=ZZ
1330 IF (L1) Z=CONJG(ZZ)
1340 J=CMPLX(0.,1.)
1350 IF (CABS(Z).GT.2.5) GO TO 250
1360 W=PI◆Z◆2/2
1370 N=0
1380 T1=1
1390 SUM=1-J◆W/3
1400 100 CONTINUE
1410 N=N+1
1420 T1=-T1
1430 MSTOP=2◆N
1440 Z1=1
1450 DO 200 M=1,MSTOP
1460 Z1=Z1◆W/M
1470 200 CONTINUE
1480 T2=2◆N+1
1490 TERM=T1◆Z1◆(1/(2◆T2-1)-J◆W/T2/(2◆T2+1))
1500 SUM=SUM+TERM
1510 IF (CABS(TERM).GE.1.E-3◆CABS(SUM)) GO TO 100
1520 FRESNL=Z◆SUM
1530 IF (L1) FRESNL=CONJG(FRESNL)
1540 RETURN
1550 250 CONTINUE
1560 F0=(1-J)/2
1570 IF (AIMAG(Z).GT.REAL(Z)) F0=(J-1)/2
1580 W=PI◆Z◆2
1590 T1=1
1600 N=0
1610 SUM=1/W-J
1620 300 CONTINUE
1630 N=N+1
1640 T1=-T1
1650 Z1=1
1660 MSTOP=2◆N
1670 DO 400 M=1,MSTOP
1680 Z1=Z1◆(2◆M-1)/W
1690 400 CONTINUE
1700 TERM=T1◆Z1◆((4◆N+1)/W-J)
1710 SUM=SUM+TERM
1720 IF (CABS(TERM).GE.1.E-3◆CABS(SUM)) GO TO 300
1730 FRESNL=F0-CEXP(-J◆W/2)/(PI◆Z)◆SUM
1740 IF (L1) FRESNL=CONJG(FRESNL)
1750 RETURN
1760 END
1770 ◆

```

1780 ♦ PLOT RESULTS

1790 ♦

1800 SUBROUTINE GRAF(IWAY)

1810 REAL L,MUREL

1820 COMMON /GEO/ L,WAVEL,ALPHA,THETA,THSTOP,THINC

1830 COMMON /MAT/ EPSREL,MUREL,TAN,TANMAG,SIG

1840 DIMENSION JSYM(5),IN(3)

1850 DATA PI /3.141592654/

1860 IN(1)='GR'

1870 IN(2)='AP'

1880 IN(3)='H'

1890 JSYM(1)='♦'

1900 JSYM(2)='+'

1910 CALL PSUB(JSYM,1,1,IN)

1920 WAV=WAVEL/1.E-6

1930 TAPER=L/1.E-6

1940 ALPH=ALPHA*180/PI

1950 IF (IWAY.EQ.1) WRITE (9,300) WAV

1960 IF (IWAY.EQ.2) WRITE (9,400) WAV

1970 WRITE (9,500) TAPER,ALPH,EPSREL,TAN,MUREL,TANMAG,SIG

1980 300 FORMAT (1X,/,15X,'FIG. EFFICIENCY VS. ANGLE OF INCIDENCE',

1990 +/,1X,'TE WAVE, WAVELENGTH= ',

2000 +F8.3,' MICRONS')

2010 400 FORMAT (1X,/,15X,'FIG. EFFICIENCY VS. ANGLE OF INCIDENCE',

2020 +/,1X,'TM WAVE, WAVELENGTH= ',

2030 +F8.3,' MICRONS')

2040 500 FORMAT (1X,'LENGTH OF TAPER= ',F8.3,' MICRONS',5X,

2050 +',HALF-ANGLE OF TAPER= ',F8.3,' DEGREES',/,1X,'DIELECTRIC CONSTANT= ',

2060 +F8.3,9X,'LOSS TANGENT= ',F8.3,/,1X,'RELATIVE ',

2070 +',PERMEABILITY= ',F8.3,7X,'LOSS TANGENT= ',F8.3,/,1X,

2080 +',CONDUCTIVITY= ',F8.3,' MHOS/METER',/)

2090 RETURN

2100 END

2110 ♦

2120 ♦ PLOT UP TO 5 FUNCTIONS ON TELETYPE

2130 ♦

2140 SUBROUTINE PSUB(JSYM,M,NUNIT,IN)

2150 DIMENSION X(330),Y(330),IDUM(330),ISYM(330),IN(3),JSYM(5)

2160 ♦

2170 ♦ JSYM=SYMBOLS TO BE USED FOR PLOTTING POINTS

2180 ♦ M=NUMBER OF FUNCTIONS TO BE PLOTTED

2190 ♦ NUNIT=NUMBER OF THE FILE CONTAINING DATA TO BE PLOTTED

2200 ♦ IN=NAME OF FILE NUMBER "NUNIT"

2210 ♦

2220 IB=0

2230 CALL DEFINE(NUNIT,IN)

2240 IF (M.GT. 5) GO TO 130

2250 IF (M.GT. 1) GO TO 90

2260 DO 80 I=1,330

2270 IF (IEOF(NUNIT).EQ. 1) GO TO 120

2280 IF (IB.EQ.1) READ (NUNIT) X(I),Y(I)

2290 IF (IB.EQ.0) READ(NUNIT,200) X(I),Y(I)

2300 80 ISYM(I)=JSYM(1)

2310 GO TO 120

2320 90 I2=0

2330 100 I=I2+1


```

2340 IF (IEDF(NUNIT) .EQ. 1) GO TO 120
2350 I1=I+1
2360 I2=I+M-1
2370 IF (IB.EQ.1) READ(NUNIT) X(I),(Y(J),J=I,I2)
2380 IF (IB.EQ.0) READ(NUNIT,200) X(I),(Y(J),J=I,I2)
2390 ISYM(I)=JSYM(1)
2400 K=1
2410 DO 110 J=I1,I2
2420 X(J)=X(I)
2430 K=K+1
2440 110 ISYM(J)=JSYM(K)
2450 IF (I .LT. 330) GO TO 100
2460 120 N=I-1
2470 WRITE(9,125)N
2480 125 FORMAT(/,'TOTAL NUMBER OF POINTS PLOTTED = ',I3)
2490 CALL PLOT(X,Y,N,ISYM,IDUM)
2500 RETURN
2510 130 WRITE(9,140)
2520 140 FORMAT('MAX. NUMBER OF CURVES = 5')
2530 200 FORMAT(6E11.6)
2540 210 FORMAT('SYMBOLIC FILE READ STATEMENT IS 6E11.6')
2550 END
2560 SUBROUTINE PLOT(X,Y,N,ISYM,IDUMMY)
2570 DIMENSION X(N),Y(N),ISYM(N),IDUMMY(N)
2580 NYDIV=7
2590 ICODE=0
2600 YTOP=0.0
2610 YBOT=0.0
2620 XRIGHT=0.0
2630 XLEFT=0.0
2640 ITIE=1H.
2650 CALL PLOTF(X,Y,N,NYDIV,ICODE,YTOP,YBOT,XLEFT,XRIGHT,ISYM,
2660 + ITIE,IDUMMY)
2670 RETURN
2680 END
2690 SUBROUTINE PLOTF(X,Y,N,NYDIV,ICODE,YTOP,YBOT,XLEFT,XRIGHT,ISYM,
2700 + ITIE,IDUMMY)
2710 DIMENSION IXFLOT(70),ISYM(N),IDUMMY(N),X(N),Y(N)
2720 DATA NBLANK /1H /,XL /70./,NXDIV /7/
2730 WRITE(9,500)
2740 N1=NYDIV*10+1
2750 YL=N1-1
2760 IF (ICODE.EQ.1) GO TO 10
2770 CALL SCALIT(X,Y,N,N,1,0,XL,NXDIV,YL,NYDIV,XLEFT,XSCALE,DX,
2780 + YBOT,YSCALE,DY)
2790 XRIGHT=XLEFT+7.0*DX
2800 YTOP=YBOT+FLOAT(NYDIV)*DY
2810 GO TO 20
2820 10 DX=(XRIGHT-XLEFT)/7.
2830 DY=(YTOP-YBOT)/FLOAT(NYDIV)
2840 XSCALE=70./(XRIGHT-XLEFT)
2850 YSCALE=YL/(YTOP-YBOT)
2860 20 TERMX=1.5-XSCALE*XLEFT
2870 TERMY=YSCALE*YTOP+1.5
2880 WRITE(9,540) YTOP,YBOT,DY,XLEFT,XRIGHT,DX
2890 WRITE(9,510)

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2900 CALL SORTN(Y,N,IDUMMY)
2910 K=10
2920 J=N
2930 JJ=IDUMMY(J)
2940 IYPLT=INT(TERM-YSCALE*Y(JJ))
2950 I=0
2960 30 I=I+1
2970 IF (I.GT.N1) GO TO 140
2980 K=K+1
2990 MARK=1H+
3000 IF (K.LT.10) GO TO 50
3010 K=0
3020 MARK=1H-
3030 50 IF (J.LT.0) GO TO 85
3040 DO 60 L=1,70
3050 60 IXPLT(L)=NBLANK
3060 MAX=0
3070 70 IF (IYPLT-I) 130,100,80
3080 80 IF (MAX.NE.0) GO TO 90
3090 85 WRITE(9,520) MARK
3100 GO TO 30
3110 90 WRITE(9,530) MARK, (IXPLT(L),L=1,MAX)
3120 IF (J.EQ.0) J=-1
3130 GO TO 30
3140 100 IJ=INT(TERM+XSCALE*X(JJ))
3150 IF (IJ.LT.1) GO TO 120
3160 IF (IJ.GT.70) GO TO 120
3170 IF (IJ.GT.MAX) MAX=IJ
3180 IF (IXPLT(IJ).NE.NBLANK) GO TO 110
3190 IXPLT(IJ)=ISYM(JJ)
3200 GO TO 130
3210 110 IXPLT(IJ)=ITIE
3220 GO TO 130
3230 120 IF (J.GT.1) GO TO 130
3240 J=-1
3250 GO TO 80
3260 130 J=J-1
3270 IF (J.LT.1) GO TO 80
3280 JJ=IDUMMY(J)
3290 IYPLT=INT(TERM-YSCALE*Y(JJ))
3300 GO TO 70
3310 140 WRITE(9,510)
3320 WRITE(9,500)
3330 RETURN
3340 500 FORMAT(/)
3350 510 FORMAT(2H+'',7(9(1H+)-1H'))
3360 520 FORMAT(A1)
3370 530 FORMAT(70A1)
3380 540 FORMAT(18HAXIS INFORMATION :/,3X,10HVERTICAL :,
3390 + 13H TOP (-) =,610.3,/,14X,12HBOTTOM (-) =,610.3,/,14X,
3400 + 13HINCREMENT = ,610.3,/,2X,25HHORIZONTAL: LEFT (') = ,610.3,
3410 + /,14X,13HRIGHT (') = ,610.3,/,14X,13HINCREMENT = ,610.3,/)
3420 END
3430 SUBROUTINE SCALIT(X,Y,N,NDIM,NCRVES,ICODE,XLONG,NXDIV,
3440 + YLONG,NYDIV,XBOT,XSCALE,DX,YBOT,YSCALE,DY)
3450 DIMENSION X(N),Y(N)

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```

3460 L=1
3470 AMAX=X(1)
3480 AMIN=X(1)
3490 DO 5 I=1,N
3500 IF (X(I).GT.AMAX) AMAX=X(I)
3510 IF (X(I).LT.AMIN) AMIN=X(I)
3520 5 CONTINUE
3530 XYLONG=XLONG
3540 IF (ICODE.EQ.-1) GO TO 65
3550 IF (ICODE.EQ.-3) GO TO 65
3560 XYN=NXDIV
3570 NXYN=NXDIV
3580 10 IF (ICODE.NE.2) GO TO 20
3590 IF (AMAX.LT.0.0) AMAX=0.0
3600 IF (AMIN.GT.0.0) AMIN=0.0
3610 20 SPREAD=(AMAX-AMIN)/XYN
3620 IF (SPREAD.LE.0.0) GO TO 150
3630 25 A=ALOG10(SPREAD)
3640 I=A
3650 AA=I
3660 AA=A-AA
3670 IF (AA.LE.0.0) AA=AA+1.
3680 A=10.**AA
3690 IF (A.GT.2.) GO TO 30
3700 AA=2./A
3710 GO TO 40
3720 30 IF (A.GT.5.) GO TO 35
3730 AA=5./A
3740 GO TO 40
3750 35 AA=10./A
3760 40 SPREAD=SPREAD*AA
3770 A=AMIN/SPREAD
3780 I=A
3790 AA=I
3800 AA=A-AA
3810 IF (AA.LE.0.0) AA=AA+1.
3820 AA=AA*SPREAD
3830 A=(AMAX-AMIN+AA)/XYN
3840 IF (A.LE.SPREAD) GO TO 45
3850 SPREAD=A
3860 GO TO 25
3870 45 YBOT=AMIN-AA
3880 SPACEL=AMIN-YBOT
3890 SPACER=YBOT+(XYN*SPREAD)-AMAX
3900 NL=SPACEL/SPREAD
3910 NR=SPACER/SPREAD
3920 MOVE=(NR-NL)/2
3930 YBOT=YBOT-FLOAT(MOVE)*SPREAD
3940 YSCALE=XYLONG/(SPREAD*XYN)
3950 DY=SPREAD
3960 GO TO (50,100), L
3970 50 XBOT=YBOT
3980 XSCALE=YSCALE
3990 DX=DY
4000 55 L=2
4010 AMAX=Y(1)

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4020 AMIN=Y(1)
4030 DO 60 J=1,NORVES
4040 I1=1+(J-1)*NDIM
4050 IN=I1+N-1
4060 DO 60 I=I1,IN
4070 IF (Y(I).GT.AMAX) AMAX=Y(I)
4080 IF (Y(I).LT.AMIN) AMIN=Y(I)
4090 60 CONTINUE
4100 XYLONG=YLONG
4110 IF (ICODE.EQ.-2) GO TO 65
4120 IF (ICODE.EQ.-3) GO TO 65
4130 XYN=NYDIV
4140 NXYN=NYDIV
4150 GO TO 10
4160 65 I=AMAX
4170 IF (AMAX.GT.0.0) GO TO 70
4180 GO TO 75
4190 70 A=I
4200 IF (AMAX.GT.A) I=I+1
4210 75 NXYN=AMIN
4220 IF (AMIN.LT.0.0) GO TO 80
4230 GO TO 85
4240 80 A=NXYN
4250 IF (AMIN.LT.A) NXYN=NXYN-1
4260 85 YBOT=NXYN
4270 NXYN=I-NXYN
4280 SPREAD=NXYN
4290 NYDIV=NXYN
4300 YSCALE=XYLONG/SPREAD
4310 GO TO (90,100), L
4320 90 XBOT=YBOT
4330 XSCALE=YSCALE
4340 DX=DY
4350 MXDIV=NYDIV
4360 GO TO 55
4370 100 RETURN
4380 150 WRITE(9,1000)
4390 RETURN
4400 1000 FORMAT(/,'THE FUNCTION APPEARS TO BE A CONSTANT',/)
4410 END
4420 SUBROUTINE SORTN(X,N,NUM)
4430 DIMENSION NUM(N),X(N)
4440 DO 10 I=1,N
4450 10 NUM(I)=I
4460 M=N
4470 45 M=M/2
4480 IF (M.LE.0) GO TO 90
4490 K=N-M
4500 DO 80 I=1,K
4510 J=I
4520 60 L=J+M
4530 NL=NUM(L)
4540 NJ=NUM(J)
4550 IF (X(NL).GT.X(NJ)) GO TO 80
4560 NUM(J)=NL
4570 NUM(L)=NJ

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4580 J=J-M
4590 IF (J.GE.1) GO TO 60
4600 80 CONTINUE
4610 GO TO 45
4620 90 RETURN
4630 END
4640 FUNCTION IREPLY(D)
4650 READ (9,3) IANS
4660 IF(IANS.EQ.1HY)GOTO2
4670 IF(IANS.EQ.1H )GOTO2
4680 IF(IANS.EQ.1HO)GOTO2
4690 IF(IANS.EQ.1HT)GOTO2
4700 IREPLY=0
4710 RETURN
4720 2 IREPLY=1
4730 RETURN
4740 3 FORMAT(A1)
4750 END

```